QUESTIONS AND ANSWERS IN

THE THEORY AND PRACTICE

OF

MILITARY TOPOGRAPHY

BY

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WITH WORKING PLANS SEPARATELY

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PREFACE.

THERE is to my mind no better way to attain proficiency in the theory of topography than to work out *without help* a series of questions and problems which embrace the whole subject. The thoughtful and aspiring student is perfectly well aware of this, and consequently I have been asked over and over again to recommend some book which gives recent examination questions and their answers. On every occasion I have had to confess my inability to do so: there is no book published, so far as I am aware, which fulfils the required conditions.

Here, then, is my excuse for bringing this volume to the notice of officers serving in, as well as those about to enter, our army, while at the same time I express a hope that it may be of some little benefit to all who use it.

While avoiding useless repetitions, the whole of the questions which have been set in recent examinations, so far as I have been able to get them, are included in this book, collected under *thirty-four groups*, each dealing with a particular branch of the subject, so that the student can by frequent practice perfect himself in details in which he is weak.

In a work of this kind, even when great care has been taken in compilation, it is almost impossible to avoid making some errors. This volume is no exception to the rule, but I hope that some excuse may be found for its many imperfections and shortcomings. I am of opinion that the only way to thoroughly eradicate mistakes is to solicit the co-operation of all students, officers, and instructors who use this book, by asking them to be so good as to point out to me any errors they discover.

J. H. BOWHILL.

BEACONSFIELD HOUSE,
TUNBRIDGE WELLS, *January* 1898.

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MILITARY TOPOGRAPHY.

GROUP I.

SCALES, PLAIN AND COMPARATIVE.

CLASS I.—Expressions.

1. Give the R.F.'s of the following scales :—
    5 inches to 1 mile.
    5 furlongs to 1 inch.
    —*Militia Competitive, March* 1883.

2. What is meant by the term R.F.? Why is it necessary that it should be stated on the plan?
Give the R.F.'s of the following scales :—
    3 miles to ·764 inches.
    ·51 inches to 9 yards. —*Ib., Sept.* 1886.

3. Give the R.F.'s of the following scales :—
    20 inches to 1 mile.
    2·5 miles to 1 inch.
    40 feet to 1 inch.
Express in yards to 1 inch, R.F. $\frac{1}{20000}$, and R.F. $\frac{1}{30000}$.
Express in inches to 1 mile, R.F. $\frac{1}{5000}$, and R.F. $\frac{1}{45000}$.
—*Ib., March* 1892.

4. Give the R.F. of—

4 miles to 1 inch and 20 inches to 1 mile.

Express in yards to 1 inch, R.F. $\frac{1}{25000}$ and R.F. $\frac{1}{70000}$, and in inches to 1 mile, R.F. $\frac{1}{12000}$ and R.F. $\frac{1}{30000}$.

—*Ib., Sept.* 1894.

5. Two plans of the same ground are drawn—one on a scale of 1·2 inches to a mile, and the other on a scale of 3 miles to 1 inch. Give the R.F. of each scale.

What distance on the ground is represented by a line $5\frac{1}{2}$ inches long on each plan?—*Promotion, Captains, May* 1894.

CLASS II.—Construction of Scales, R.F. given.

1. A man steps 105 paces to 100 yards, and a horse covers the same ground in 90.

Make comparative scales of paces. R.F. $\frac{1}{10890}$.

—*Promotion, Lieutenants, Nov.* 1891.

2. What is a "representative fraction"?

Construct scales for a map with a R.F. $\frac{1}{2534 \cdot 4}$ to read yards and mètres.

1 metre = 39·37 inches. —*Ib., May* 1892.

3. Construct a scale of $\frac{1}{3750}$ to show 900 paces.

A pace = 30 inches.

—*Admission Staff College, June* 1882.

4. The representative fractions of two plans of a Russian fort are $\frac{1}{800}$ and $\frac{1}{1260}$.

Construct a scale of French toises, 80 toises long, for the former, and one of Russian archines, 300 archines long, for the latter.

One toise = 2·13142 English yards.
One archine = ·7777 " "

—*Ib., June* 1887.

5. Draw a scale of yards suitable for examining a French map, R.F. $\frac{1}{20000}$.—*Ib.*, *May* 1892.

6. On a French map $\frac{1}{10000}$ the distance between A and B measures 9·216 inches.

Construct a scale of yards for it, the smallest subdivision to show 50 yards.

What is the distance in yards from A to B?—*Ib.*, *May* 1891.

7. Construct comparative scales suitable for sketching on horseback. R.F. $\frac{1}{15000}$.

You ascertain that in 400 yards your horse takes 160 strides at a canter, 360 steps at a walk, and you rise 120 times when trotting.

8. Construct comparative scales of paces for the following; R.F. $\frac{1}{7920}$:—

(*a*) A horse walking between two milestones takes 1680 steps.

(*b*) A man walking the same distance takes 1920 paces.

9. Construct a scale of revolutions for a cyclist whose front wheel measures 104 inches in circumference. R.F. $\frac{1}{12400}$.

Comparative to this, construct a scale for horseback sketching when your horse takes 1680 steps in 1 mile.

10. A certain scale is marked R.F. $\frac{1}{5760}$, and shows 2400 units of some sort, not stated. The length of the scale is 5 inches.

What is it a scale of?

11. A certain scale is marked R.F. $\frac{1}{63360}$, and shows 42 units of some kind, not stated. The length of the scale is 5·25 inches.

What is it a scale of?

12. A certain scale is marked R.F. $\frac{1}{15000}$, and shows 1800 units of some kind, not stated. The length of the scale is 4·7244 inches.

What is it a scale of?

CLASS III.—Construction of Scales, R.F. not given.

1. Construct a scale of Russian versts comparative to a scale of 2 miles to 1 inch, and give its R.F.

One Russian verst is 1166·6 English yards.

A length of 20 versts is to be shown.

—*Militia Competitive, March* 1884.

2. On an old German map the distance between two villages connected by a straight road is found by measurement to be 3·45 inches. The real distance is stated to be $1\frac{3}{4}$ German "meile."

The German meile is known to be equal to 10,000 of the old German "schritt," which was equal to 29·65 English inches.

Construct a scale of English miles for the map, and give its R.F. and also the distance between the two villages in English miles.—*Ib., March* 1885.

3. A sketch is found to have no scale or R.F. marked on it. The distance, however, between two points represented on the sketch as 2·75 inches apart, is measured on the ground, and found to be 655 yards.

Construct a scale for the sketch, and give its R.F.

—*Ib., March* 1887.

4. On examining a French plan, I find only a scale of decimètres, 15 to 1 inch.

Supply a comparative scale of English feet, the decimètre being equal to ·327 of an English foot.

Show 30 feet, and give the R.F.—*Ib., March* 1890.

5. On a plan a distance known to be 2150 yards is found to measure ·83 inches.

Draw in ink a scale showing miles, and give the R.F.

Ib., Sept. 1892.

6. The distance between two places on a French map measures 5 English inches, and from a scale attached to the plan is found to be 1260 mètres.

Construct a scale of English yards for the plan, and give its R.F.

1 mètre = 39·37 inches. —*Ib., March* 1895.

7. A map is drawn on a scale such that 1012 yards on the ground are equal to 3·45 inches on the map.

Draw the scale of the map reading to 100 yards.

—*Ib., March* 1896.

8. Construct a scale of (*a*) French mètres and (*b*) English chains, to suit a Russian map on which 10 versts are represented by 1 archine. Give the R.F.

1 verst = 500 sagene.
1 sagene = 3 archine.
1 chain = 66 feet.
1 mètre = 39·37 inches. —*Ib., Sept.* 1896.

9. From a point X to another point Y on an unfinished sketch the distance is 3·66 inches.

On pacing from X to Y the distance is found to be 640 paces of 33 inches each. Write down the scale and R.F.

—*Promotion, Lieutenants, Nov.* 1891.

10. Two points are known to be 1575 feet apart, the distance between them on a plan being 1·50 inches.

Construct a scale of yards to suit the plan and express it in inches to a mile, and give its R.F.

—*Promotion, Captains, May* 1892.

11. You are desired to make a sketch on horseback on a scale of 3 inches to one mile, and you ascertain that your horse, when walking, covers a quarter of a mile in 407 steps, and when trotting in 271.

Construct suitable scales.—*Ib., May* 1892.

12. The distance between two points on a Russian map 8 versts apart is found to be 2·65 inches.

Construct a comparative scale to show miles and quarter miles, and give the R.F.

1 verst = 500 sagene.
1 sagene = 7 feet.

—*Promotion, Lieutenants, Nov.* 1892.

13. A map is drawn on such a scale that 469·3 yards on the ground is represented by 1·2 inches on the map.

Draw a scale for the map.—*Promotion, Captains, May* 1895.

14. Draw a comparative scale of mètres (showing 1600 mètres) for an English map made on a scale of 6 inches to 1 mile, and give its R.F.

1 mètre = 39·37 inches.

—*Admission Staff College, June* 1883.

15. The distance between two places on a French plan measures 4·96 English inches, and from a scale of mètres attached to the plan is found to cover a length of 1260 mètres.

Construct a scale of English yards for this plan, and give its R.F.

1 mètre = 39·37 inches. —*Ib., June* 1889.

16. In a foreign country the only map available is one with a scale on which a thousand mètres = ·45 inches.

Draw this scale, and construct a comparative scale reading to 100 yards.

1 mètre = 39·36 inches. —*Ib., May* 1894.

17. The scale of a map is 3 miles to 1 inch.

Construct a comparative scale of versts.

1 verst = 500 sagene.

1 sagene = 84 inches.

18. A scale of miles is drawn on a map, but its R.F. is not stated. On applying a scale of yards 6 inches to one mile, it is found that 300 yards is the same as one mile on the map scale. Supply its R.F.

19. You have a Danish measure similar to our foot-rule, which is divided into tomme.

On applying this rule to a scale on a Danish map you find that a distance representing one mil measures 16 tomme.

You know that 1 mil contains 2000 rode and 1 rode = 144 tomme.

Construct a scale of yards for the map, and give its R.F.

20. A French contoured map is marked V.I. 5 mètres, but no scale is given. On an English map of the same ground marked "R.F. $\frac{1}{15288}$, v.i. 30 feet," the contours are found to be at the same horizontal distance apart as those on the French map.

Construct a scale of yards for the French map, and give the R.F.

1 mètre = 39·37 inches.

GROUP II.

DIAGONAL SCALES.

1. Construct a scale of 9 miles to 1 inch to show furlongs diagonally, and give the R.F.

Make the scale 60 miles long, and thicken on it a length corresponding to 26 miles 5 furlongs.

—*Militia Competitive, Sept.* 1888.

2. The distance between two forts on a French map measures 12·4 English inches, and from a scale of mètres attached to the map is found to cover a length of 1660 mètres.

Draw a scale of English yards for the map by which single yards can be measured.

Show a length of 800 yards, and give the R.F.

1 mètre = 39·37 inches. —*Ib., Sept.* 1892.

3. A map drawn to a scale of $\frac{1}{7920}$ is to be copied to four times the size of the original.

Make a scale for the copy to read hundreds, tens, and single yards.—*Ib., Sept.* 1895.

4. The distance between two points is known to be 3080 yards, and the distance on the map is found to be 5·25 inches.

Construct a scale of feet for the map.

—*Promotion, Lieutenants, May* 1892.

5. Explain the use of the diagonal scale given on the ordinary military protractor, and construct a scale of yards to show single feet diagonally. R.F. $\frac{1}{360}$.

—*Promotion, Captains, Nov.* 1892.

6. Construct a diagonal scale (by which single feet can be measured) for a map on which 154 feet are represented by 2·6 inches.

Show 400 feet, and thicken the line corresponding to 3·67 inches.

Figure your scale correctly, and give the R.F.

—*Admission Staff College, June* 1885.

7. Construct a scale to show miles, furlongs, and chains diagonally. R.F. $\frac{1}{60000}$.

8. Construct a diagonal scale to show single mètres. R.F. $\frac{1}{1200}$.

1 mètre = 39·37 inches.

9. Draw the scale you would adopt in order that the plan of a district, 17 miles long and 13 miles wide, might be made on a sheet of paper 10 inches long and $7\frac{1}{2}$ inches wide.

The plan is to be drawn to the largest possible scale.

Divide the scale so that miles, furlongs, and single chains can be measured.

GROUP III.

VERNIER SCALES.

1. Construct a vernier to read eighths of a primary scale, the latter being 3 inches long and divided into 12 parts. Make the vernier read in the same direction as the primary scale, and let it indicate a reading of $4\frac{7}{8}$ths.

—*Militia Competitive, Sept.* 1893.

2. Draw full size a portion of a primary scale graduated to $\frac{1}{10}$ inch, showing a vernier attached to read to $\frac{1}{200}$ inch in the same direction as the primary. Figure your finished drawing so that it records a reading of 1·365 inches, marking with a cross the divisions showing it.—*Ib., Sept.* 1896.

3. A vernier is required to read sixths of a primary scale, the latter being $2\frac{1}{2}$ inches long and divided into 10 parts. Construct it so as to read in the *contrary* direction to the primary scale, and let it indicate a reading of $8\frac{5}{6}$ths.

—*Ib., Dec.* 1893.

4. Construct a scale of revolutions for a cycle wheel of 105 inches circumference, for use with a map, R.F. $\frac{1}{50000}$, and attach a vernier to show divisions of 10 revolutions.

5. Construct a scale of yards, R.F. $\frac{1}{2000}$, and supply it with a fixed vernier and also with a sliding vernier both constructed to read single yards. Let the sliding vernier indicate a reading of 222 yards. Let both verniers read in the *same direction* as the primary scale.

6. Construct a scale showing miles and furlongs, R.F. $\frac{1}{72000}$. Supply this scale with a sliding and a fixed vernier to read chains. Let both verniers read in the *opposite direction* to the primary scale, and let the sliding vernier indicate a reading of 383 chains.

7. A scale has divisions of $\frac{1}{20}$ inch marked on it. A sliding vernier is fitted to this scale, and it is observed that 5 divisions on the vernier are equal in length to 4 divisions on the primary scale.

To what parts of an inch does the vernier read?

GROUP IV.

SCALES DEDUCED FROM AREAS.

1. An area of four square miles is represented on a map 12 inches by 10 inches.

Draw a scale of yards to read the map, and give the R.F.

—*Militia Competitive, March* 1891.

2. Draw a suitable scale for a map 8 inches long and 6 inches broad, on which 3 square miles of country are shown.

—*Ib., Sept.* 1895.

3. What is the scale of a map which is 18 inches long and 16 inches broad and is known to contain an area of 18 square miles?

Construct a suitable French scale for the above to show mètres.

1 mètre = 39·4 inches.

—*Promotion, Captains, May* 1893.

4. A map is 30 inches long and 20 inches wide and represents an area of one square mile.

Draw a scale of yards for the map, and mark the length of a line measuring 275 yards.

—*Admission Staff College, June* 1886.

5. The size of the plan of a piece of ground containing 20 acres is 7 inches by 5 inches.

Draw a plain scale of feet.

4840 square yards = 1 acre. —*Ib., June* 1888.

6. The plan of a piece of ground containing 40 acres measures 25 inches by 24 inches.

Draw a scale for the plan. Give the R.F.

4840 square yards = 1 acre. —*Ib.*, *June* 1890.

7. A map 18 inches long by 8 inches broad represents 16 square miles.

On what scale is it drawn?

8. A map, the sides of which measure 5 inches by 3 inches, represents $\frac{3}{4}$ of a square mile of country.

What is the R.F.?

9. A map which measures 12 inches by 15 inches represents 5 square versts.

Draw a suitable scale of yards for the map, and give its R.F.

1 verst = ·66 miles.

10. A plan 8 inches long and $6\frac{1}{4}$ inches broad represents an area of 10 square miles.

Construct a scale of yards for it, and give the R.F.

11. A map is 36 inches long and 30 inches broad. It represents an area of 25 acres.

Draw a scale for the map to show yards and feet diagonally.

1 acre = 4840 square yards.

GROUP V.

TIME SCALES.

1. A column of troops marches at the rate of $2\frac{3}{4}$ miles per hour.

Construct a scale of time to measure intervals of 10 minutes. Scale 10 miles to 1 inch.

—*Militia Competitive*, *Sept.* 1883.

2. A column of troops marches at the rate of 3 miles an hour.

Construct a scale of time to measure intervals of 10 minutes. Scale 10 miles to 1 inch.—*Ib.*, *Sept.* 1885.

3. Construct a time scale for a map, R.F. $\frac{1}{100000}$, to read hours and quarter hours, on the following information: To march from A to B, two places on the map, occupies 2 hours 15 minutes, and the distance from A to B is 5 miles 6 furlongs.—*Promotion, Lieutenants*, *Nov.* 1894.

4. A horse trots 225 yards a minute.

Construct a time scale adapted to this rate. R.F. $\frac{1}{15000}$. Let the scale be long enough to show 10 minutes.

5. A horse canters 290 yards a minute.

Construct a suitable time scale, R.F. $\frac{1}{20000}$. Let the scale be long enough to show 10 minutes.

6. A horse canters 11 miles and trots 8 miles an hour.

Construct comparative time scales suited to these rates. R.F. $\frac{1}{120000}$.

7. Draw comparative time scales for infantry marching at the rate of 3 miles an hour and cavalry marching at 5 miles an hour. R.F. $\frac{1}{30000}$.

8. A time scale has been made to suit the rate of going of a horse which trots 10 miles an hour. The length of the scale is 6 inches, and it shows 9 minutes.

What is the R.F.?

9. Draw a time scale for a cyclist who travels at the rate of 12 miles an hour. R.F. $\frac{1}{100000}$.

GROUP VI.

CORRECTION OF SCALES MADE FROM WRONG PREMISES.

1. After making a sketch which you intended to be at the scale of 8 inches to 1 mile, you test your pacing and find that instead of pacing yards as you supposed, you take 105 paces in 100 yards.

Draw a scale of yards by which distances on your sketch may be correctly measured.—*Militia Competitive, Sept.* 1887.

2. Supposing that the distances in a diagram differ from those of an accurate survey of the same ground. The distance from D to F is 810 yards, but the correct distance should be 854 yards. The scale of the diagram was intended to be 6 inches to 1 mile.

Draw a correct scale for the diagram, and give its R.F. —*Ib., Sept.* 1890.

3. The distances on the accompanying diagram when compared with the Ordnance map are found to show a constant error. For instance, A B is shown as 1200 yards, but the actual distance is 1260. The scale of the diagram was intended to be 4 inches to 1 mile.

Draw a scale for the diagram so that distances on it may be correctly measured, and give the R.F.—*Ib., Sept.* 1893.

4. In accordance with orders you sketch a position, scale $\frac{1}{10560}$. On giving in your work an error is found to exist throughout it. Your pacing has been short, and in all your measurements you have measured 95 yards as 100 yards.

Give the R.F. of the scale which will agree with the work you have done.—*Ib.*, *March* 1894.

5. On comparing a sketch you have done, at 6 inches to 1 mile, with the Ordnance Survey of that portion of ground, you discover that all your distances on the sketch differ in the same proportion with those on the Ordnance Survey. For instance, 570 yards on the Ordnance Survey are represented on your sketch as 555 yards.

Draw a correct scale for the sketch, and give the R.F.

—*Promotion, Lieutenants, May* 1893.

6. On comparing with the Ordnance Survey a sketch which was intended to be drawn at a scale of 9 inches to 1 mile, you find that a constant error occurs in the distances. For instance, you find that a distance which, according to the scale given on the sketch, is 990 yards, should be 925.

Draw a correct scale of yards suitable to the sketch.

By how much per cent too long or too short were the paces of the man who made the sketch?

—*Admission Staff College, June* 1888.

7. You are ordered to make a sketch on a scale of 6 inches to 1 mile, but on subsequently comparing your work with the Ordnance map, you find a constant error in the distances shown on it. For instance, a distance given by the scale on your sketch as 1100 yards is found to be really 1155 yards.

Draw a scale for your sketch so that the distances on it may be correctly measured, and give the R.F.

—*Ib.*, *August* 1895

8. Construct a scale of paces for a sketch made by a surveyor under the following circumstances: he used a scale of paces (30 inches to 1 pace), R.F. $\frac{1}{7920}$, but on checking his

paces afterwards he found that instead of taking paces of 30 inches as he supposed, he took 120 paces in 110 yards.

Give the R.F.

9. When pacing a base a sketcher makes the length 1320 paces of 33 inches each, but on comparing this distance afterwards with the Ordnance Survey he found the correct length of the base was 1100 yards.

Give the R.F. of the correct scale for the sketch if the sketcher used a scale of paces (33 inches) comparative to a scale of 6 inches to 1 mile.

10. A sketcher when making a sketch used a scale of 8 inches to 1 mile. His pacing was long, and consequently his distances were all wrong in the proportion of 12 to 11.

What is the correct R.F.?

11. A sketch was intended to be drawn to a scale of $\frac{1}{12672}$, but the correct R.F. was found to be $\frac{1}{11968}$. The sketcher thought he paced yards.

What was the correct length of his pace?

12. After making a contoured sketch intended to be drawn at a scale of 8 inches to 1 mile, the sketcher found by comparison with the Ordnance Survey of the same ground that, in consequence of a mistake regarding the length of his pace, his distances and heights were all wrong in the same proportion. For instance, a point on the O.S. marked 170 feet appeared on his sketch as 180 feet.

Construct a scale of yards to suit the sketch.

GROUP VII.

SCALES OF HORIZONTAL EQUIVALENTS.

1. On a map of Paris, scale $\frac{1}{25000}$, the contours are marked as being at vertical intervals of 60 pieds.

Construct a scale of H.E. in English yards to suit the map.

1 pied = 10·82 inches.

Show both calculations and scale.

—*Militia Competitive*, *Sept.* 1886.

2. Construct a scale showing the H.E. for 1°, 3°, 5°, 8°, 12°, and 20°, for a plan drawn at a scale of $\frac{1}{26400}$, and on which the contours are represented at vertical intervals of 50 feet. Show both calculation and scale.—*Ib.*, *March* 1887.

3. Explain the meaning of the term "horizontal equivalent."

Construct a scale of H.E. for 2°, 3°, 5°, 8°, and 12°, for a foreign map drawn on a scale of $\frac{1}{30000}$, on which the contours are shown at 20 mètres V.I.

1 mètre = 39·37 inches. —*Ib.*, *Sept.* 1892.

4. Construct a scale of H.E. for the diagram (see diagram I.) under the following conditions—viz.: Scale of diagram, $\frac{1}{15000}$; contours, 10 mètres V.I. Equivalents for 2°, 3°, 5°, 8°, and 12°, to be shown in yards.

1 mètre = 39·37 inches. —*Ib.*, *Sept.* 1893.

5. It being necessary for you to read the slopes on a foreign plan, the R.F. of which is $\frac{1}{15000}$, and the V.I. 12 mètres (1 mètre = 39·37 inches).

Construct a scale to enable you to read slopes of 2°, 7°, 10°, and 18°, and show how you obtain the H.E.'s.

—*Ib.*, *March* 1892.

6. Presuming the scale of a diagram to be 5·5 inches to 1

mile, construct a scale of slopes to read the diagram, and give the H.E. in yards for 5°, 7°, and 18°. The V.I. is 20 feet. Show how you arrive at your answer.—*Ib.*, *Sept.* 1890.

7. Two maps, No. 1 and No. 2, are drawn to the same scale. On No. 1 the contours are normal, and it is found that for a slope of $1\frac{1}{2}°$ the distance on the map between the contours is 152·8 yards. On No. 2 map the contours are not normal, and two adjacent contours have heights of 30 and 45 marked upon them respectively.

(*a*) What is the R.F. of the maps?

(*b*) Draw a scale of H.E. for each map for degrees of slope of 1°, 2°, 5°, 10°, 15°, specifying which scale is for which map.—*Ib.*, *Sept.* 1896.

8. The scale of a foreign map is $\frac{1}{10000}$, and the contours are at V.I. of 10 mètres.

Construct a scale of H.E. for slopes of 3°, 5°, 7°, 10°, and 15°.

1 mètre = 39·4 inches.

—*Promotion, Lieutenants, Nov.* 1891.

9. Explain the principle on which scales of slope or horizontal equivalents are constructed.

Construct a scale of H.E. for slopes up to 8° for contours at 50 feet V.I., on a scale of 3 inches to 1 mile.

—*Promotion, Captains, May* 1892.

10. The distance vertically between the contours on a French map, R.F. $\frac{1}{10000}$, is 10 mètres.

Construct a scale of slopes showing 3°, 5°, 8°, 10°, and 13°.

1 mètre = 39·37 inches.

—*Promotion, Lieutenants, Nov.* 1892.

11. What do you understand by the term "horizontal equivalent"?

Explain the principle on which scales of H.E. are made, and why it is advantageous to have a normal scale.

—*Promotion, Captains, Nov.* 1892.

12. Explain the principle on which scales of H.E. are constructed, and draw a scale of H.E. suitable to a scale of 5 inches to 1 mile with contours at the normal distance apart.
—*Ib.*, *May* 1893.

13. The contours of a sketch drawn on a scale of 4 inches to 1 mile are 50 feet apart.

Construct a scale of slopes for the same showing 2°, 5°, 7°, and 10°.—*Promotion*, *Lieutenants*, *May* 1894.

14. Draw a scale of H.E. for slopes of 1°, 3°, 5°, and 7°, for a map of which the R.F. is $\frac{1}{2000}$, and on which two adjacent contours are figured 134 and 142.
—*Promotion*, *Captains*, *Nov.* 1894.

15. Construct a scale of H.E. on a scale of 3 inches to one mile, showing the equivalents for 3°, 5°, 7°, and 10°, the V.I. being 20 feet.—*Promotion*, *Lieutenants*, *May* 1895.

16. Draw a scale of H.E. suitable for examining the accompanying diagram (see diagram II.)

1 mètre = 39·37 inches.

—*Admission Staff College*, *May* 1892.

17. What is the normal scale of H.E.? What are its advantages?

On a certain map on which this normal scale is used, the H.E. for 1° of slope is 229·2 yards. What is the scale of the map?—*Ib.*, *May* 1894.

18. Construct a scale of H.E. for a sketch, the R.F. of which is $\frac{1}{20000}$, and the vertical interval of the contours is 12 mètres. Equivalents for 3°, 5°, 8°, and 12° to be shown in yards.

1 mètre = 39·37 inches. —*Ib.*, *Aug.* 1895.

19. On a Danish contoured map the horizontal distance

between two consecutive contours representing ground known to slope at 2° is found when measured off the scale attached to the map to be 143·25 favn. On the scale a distance of 1000 favn is represented by $5\frac{1}{4}$ inches.

Make a scale of H.E. for the map, and state the V.I.

20. On a Spanish contoured map the V.I. is stated to be 20 palms. The distance between two adjacent contours is found to measure 286·5 palms on the scale attached to the map.

What is the slope of the ground at the part measured?

State how you would construct a scale of H.E. for this map from the above information if you had no scale of English inches and you do not know the equivalent of a Spanish palm in English measurement.

21. You have not access to a certain map, but you have a section made on a line on the map. This section bears the information that heights are to distances as 10 to 1. The section lines are marked 300 feet, 325 feet, 350 feet, &c., and they are placed ·25 of an inch apart.

Construct a scale of H.E. for the map showing 1° to 5°.

22. An officer when making a sketch intended to be at a scale of 8 inches to 1 mile, with normal contours, paced yards as he thought. He afterwards found that his paces were only 32 inches long.

Construct a scale of H.E. to read the sketch and give the V.I. Show your calculations.

23. An officer made a sketch which he intended to be at a scale of 4 inches to 1 mile, with contours at 20 feet V.I. He afterwards compared his sketch with a correct one, and found that his distances were all too short in the proportion of 10 to 11.

What was the correct V.I.?

Construct a scale of slopes for the map showing 1° to 5°

24. An Austrian map is marked "R.F. $\frac{1}{14400}$, V.I. 25 Fuss."

Draw a scale of slopes for it showing 1° to 5°.

1 fuss = 1·04 feet.

25. Construct a scale of slopes for a Spanish map on which a distance of 1720 palms is represented by 3 inches. The V.I. is 20 palms.

26. A map contoured on the normal system bears neither scale nor R.F. An officer studying the map is not in possession of a normal scale of H.E. He measures the distances on the map between successive contours along a straight road, and finds them to be ·87 inches, ·52 inches, ·43 inches, and ·65 inches.

Give the slope of the road at each of the places measured.

27. A map, R.F. $\frac{1}{10000}$, V.I. 25 feet, has been copied to $\frac{1}{4}$ of its area. The copy contains the same number of contours as the original.

Construct a scale of H.E. for the copy showing 1° to 5°.

28. A contoured map, R.F. $\frac{1}{10560}$, V.I. 25 feet, has been copied to a scale of $\frac{1}{15000}$. The copy contains the same number of contours as the original.

Construct a scale of H.E. for the copy showing 1° to 5°.

29. To a contoured map, R.F. $\frac{1}{126720}$, you apply the normal scale of H.E., and you find that a certain slope reads 3°. You know that the real slope at this place is 2·4°.

Construct a scale of H.E. for the map showing 1° to 5°.

30. On a Japanese map is drawn a scale of shaku, and it also bears the information that the vertical interval between the contours is 20 shaku. On applying an English footrule to the scale it is found that 4500 shaku are represented by a line 6 inches long.

Construct a scale of slopes for the map showing 1° to 5°.

GROUP VIII.

COPYING MAPS.

1. A drawing marked with the R.F. $\frac{1}{20000}$ is to be copied on a scale of 3 inches to 1 mile.

If squares of 1 inch side be drawn on the original, what must be the size of the squares on the copy?

—*Militia Competitive*, *Sept.* 1886.

2. A drawing marked with the R.F. $\frac{1}{15000}$ is required to be copied on a scale of 3 inches to 1 mile.

If squares of 1 inch side be drawn on the original, what must be the size of the squares on the copy?

—*Ib.*, *March* 1890.

3. Explain fully how you would copy by means of squares, on a scale of 8 inches to 1 mile, a French map having an R.F. $\frac{1}{10000}$.—*Ib.*, *March* 1892.

4. A drawing on a scale of 5 inches to 1 mile is required to be reproduced at R.F. $\frac{1}{21120}$. The original is prepared with 1 inch squares.

What will be the size of those prepared for the copy?

—*Ib.*, *Sept.* 1892.

5. To illustrate a report you have prepared a map on a scale of $\frac{1}{100000}$, the exact limits of which come within a rectangular margin 3 inches by 4 inches. You are told, however, that this map is too small, and that you are to enlarge it to $2\frac{1}{2}$ times the scale.

What will be the R.F. of your enlarged map, and the dimensions of its margins? —*Ib.*, *March* 1893.

6. Reproduce by the method of squares the portion of the diagram (see diagram I.) which embraces the hill tops A, D, and F, bounded by the stream on one side, and the road *b c*

on the other, and shade it as neatly as you can in mezzotint, adhering as closely as possible to the scale of shade.

—*Ib.*, *Sept.* 1893.

7. A plan is to be reduced from a scale of 3 inches to 1 mile to that of 3 miles to 1 inch.

With what sized squares would you prepare the original and the copy?—*Ib.*, *Sept.* 1894.

8. A Prussian plan measuring 5·5 inches in length, representing 1300 schritte on the ground, is to be reproduced to a scale of $\frac{1}{12000}$. The original was prepared with one-inch squares.

What must be the size of the squares prepared for the copy?

1 schritte = 30 inches. —*Ib.*, *March* 1895.

9. The map (see diagram XV.) is to be reproduced on a scale of $\frac{1}{15840}$. Actually do this as regards the portion enclosed within the rectangle ABCD, drawing your reproduction on the east margin of the map. The scale of the map is $\frac{1}{10560}$.—*Ib.*, *March* 1896.

10. Suppose the paper on which you are writing your answers (say 12 inches by 8 inches) to represent a map on a scale of $\frac{1}{2500}$. You are ordered to reproduce this map on a scale of $\frac{1}{20000}$. Show what space the map drawn on this latter scale will occupy.—*Promotion*, *Lieutenants*, *May* 1892.

11. What method would you adopt for the enlargement or reduction of maps to any given scale for military purposes? Explain briefly the principle on which it is based.

A plan, the R.F. of which is $\frac{1}{10560}$, is to be copied at R.F. $\frac{1}{42240}$; how would you propose to proceed?

—*Promotion*, *Captains*, *Nov.* 1892.

12. The scale of a map is $\frac{1}{20000}$. A copy of the same is required on a scale of 6 inches to 1 mile. Explain how to make this copy.—*Promotion*, *Lieutenants*, *Nov.* 1893.

13. Explain fully how to enlarge or reduce, to any given scale, a map drawn on another scale.—*Ib., Nov.* 1894.

14. A map drawn on a scale of $\frac{1}{63360}$ is to be copied to a scale of $\frac{1}{20000}$.

What sized squares would you use to make the copy?

—*Ib., May* 1895.

15. A map, scale $\frac{1}{15000}$, is to be copied on a scale of $\frac{1}{10560}$.

If squares of 1 inch side are made on the original map, what will be the size of the squares for the copy?

—*Ib., Nov.* 1896.

16. A drawing marked R.F. $\frac{1}{20000}$ is to be copied on a scale of 4 inches to 1 mile.

If squares of 1 inch side be drawn on the original, what must be the size of the squares on the copy?

—*Admission Staff College, June* 1890.

17. By what means can maps be enlarged or reduced? Explain fully any one of the several methods which give accurate results.—*Ib., May* 1891.

18. An Italian map is made on a scale of $\frac{1}{100000}$. It is required to copy it on a scale of $\frac{1}{31680}$.

What sized squares will be convenient to use when executing the drawing?—*Ib., May* 1893.

19. A foreign map marked with the R.F. $\frac{1}{13000}$ is to be copied on a scale of 4 inches to 1 mile.

If squares of 1 inch side be drawn on the copy, of what length in inches must the sides of the squares be on the original?—*Ib., August* 1895.

20. A map, the sides of which measure 6 inches by 4 inches, R.F. $\frac{1}{10560}$, has been copied so that the sides of the copy measure 15 inches by 10 inches.

What is the R.F. of the copy?

21. Two copies of a map which measures 10 inches by 8 inches are to be made, one to 4 times the scale, and the other to 4 times the area.

(1) What will the lengths of the sides of each of these two copies be?

(2) If squares of $\frac{1}{4}$ inch side are drawn on the original, what squares should be drawn on each of the copies?

(3) If the original was drawn to a scale of 3 inches to 1 mile, give the R.F. of each of the copies.

22. Two copies of a map which measures 18 inches by 24 inches are to be made, one to $\frac{1}{9}$ the scale and the other to $\frac{1}{9}$ the area.

(1) What will the lengths of the sides of each of these copies be?

(2) If squares of 2·25 inches side were drawn on the original, what squares would you draw on each of the copies?

(3) If the original was drawn on a scale of $\frac{1}{5280}$, what would the R.F. of each copy be?

23. A copy to the largest possible scale of a map, R.F. $\frac{1}{15840}$, the sides of which measure 10 inches by 8 inches, is to be made on a sheet of paper measuring 14 inches by 10 inches.

Say what the sides of the copy will measure in inches, and give the R.F.

24. A map drawn to a scale of $\frac{1}{7920}$ has been copied to a scale of 8 yards to $\frac{1}{8}$ inch.

If the copy measures 16 inches square, what was the length of the sides of the original map?

25. A map, R.F. $\frac{1}{15840}$, is 16 inches long, and represents an area of 9 square miles. It is to be copied to twice its scale and also to twice its area.

What will the sides of these two copies measure in inches?

If squares of $\frac{1}{2}$ inch side have been drawn on the original, what should the sides of the squares on each of the two copies measure?

State the R.F. of each copy.

26. A drawing on a scale of 5 inches to 1 mile is to be reproduced at $\frac{1}{21120}$.

The original is prepared with one-inch squares; what squares should be drawn on the copy?

What proportion will the space (on paper) occupied by the copy bear to that of the original?

27. A map, R.F. $\frac{1}{20000}$, is 15 inches long and 7 inches wide. A portion representing 5 square miles is to be cut off from the right hand end of the map and copied to a scale of 6 inches to 1 mile.

What will the sides of the copy measure?

28. A square portion of a map, R.F. $\frac{1}{18480}$, containing $\frac{25}{16}$ square miles, is to be copied to 4 inches to 1 mile.

If squares of $\frac{3}{7}$ inch side are drawn on the original, what squares should be drawn on the copy, and what will the sides of the copy measure?

29. A map, R.F. $\frac{1}{10560}$, measuring 6 inches by 4 inches, is copied on a sheet of paper, area $37\frac{1}{2}$ square inches.

What is the R.F. of the copy, and what would the length of the sides be?

30. Copy diagram XVI. to a scale of $\frac{1}{15000}$. Let the copy be fairly exact and complete in all particulars. The contours are at 20 feet V.I.

The student should now practise an example in copying a map when the number of contours in the copy will differ from those in the original.

31. Suppose that the R.F. of diagram X. is $\frac{1}{6336}$, and the contours are at 20 feet V.I. Copy the diagram to R.F. $\frac{1}{6336}$, with normal contours.

32. Suppose the R.F. of diagram X. is $\frac{1}{10560}$, with normal contours, copy it to R.F. $\frac{1}{15840}$, with normal contours.

GROUP IX.

CONSTRUCTION AND DRAWING OF SECTIONS.

1. Draw a section from the following conditions :—

From	A to B,	200	yards—	rise.
"	B to C,	140	"	"
"	C to D,	70	"	"
"	D to E,	50	"	"
"	E to F,	30	"	level.
"	F to G,	70	"	fall.
"	G to H,	100	"	"

Scale 12 inches to 1 mile, usual vertical intervals; heights to distances as 3 to 1.—*Militia Competitive, March* 1884.

2. Draw seven parallel lines at the following distances apart—viz.: $\frac{1}{5}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{2}{3}$, $\frac{3}{4}$, and $\frac{1}{2}$ an inch. Assuming that these represent contour lines at normal vertical intervals on a scale of 6 inches to 1 mile, the first being the crest contour, draw a right section of the ground they represent. Heights to distances as to 6 to 1.—*Ib., Sept.* 1886.

3. Draw a section from the following data: Scale for horizontal distances, $\frac{1}{2640}$; scale for vertical distances, $\frac{1}{480}$; V.I. of contours, 15 feet.

A is 75 feet above datum level. From A to B there is a fall of 30 feet with H.E. 50 yards, BC is level for 27·5 yards, C to D a rise of 20 feet with H.E. 35 yards, D to E a fall of 52·5 feet with H.E. 55 yards, E to F is level for 27·5 yards, F to G a rise of 7·5 feet with H.E. 25 yards, G to H a fall of 20 feet with H.E. 100 yards.

From the data above given, give the degrees of slope and corresponding gradients for AB, CD, DE, FG, and GH.

—*Ib., March* 1891.

4. Draw a section on the line AC (diagram I.) under the

following conditions: Scale of the diagram 6 inches to 1 mile; contours at 25 feet V.I.; heights to distances as 6 to 1.

Figure the section correctly, taking the lowest contour shown on the diagram as 50 feet above sea level.

—*Ib.*, *Sept.* 1893.

5. To a scale of 8 inches to 1 mile draw a line AB, 1200 yards long. From A as centre describe arcs cutting the line AB, with radii of ·9, 1·1, 1·4, 1·8, and 2·5 inches, and from B as a centre describe three arcs with radii of ·4, 1, and 2 inches. These curves represent portions of contours, and the point where the two series of curves approach nearest to each other must be considered as a col between two hills.

Draw a section on the line AB, with the following conditions: Heights to distances as 5 to 1; V.I. 20 feet.

—*Ib.*, *March* 1892.

6. Draw seven straight and parallel lines at the following distances apart—viz.: ·2, ·3, ·45, ·6, ·75, and ·9 of an inch respectively, and assume these to be contour lines on a hill-side, the first being the crest contour.

On a line inclined at 45° with the direction of these contours plot a section on the following conditions: Scale of plan $\frac{1}{10560}$; contours normal; heights to distances as 9 to 1.

—*Ib.*, *Sept.* 1892.

7. Make a section on the line AB of the accompanying sketch (diagram III.) Heights to distances as 6 to 1.

Figure the heights along this section. The large loch is 100 feet above the datum level.—*Ib.*, *March* 1894.

8. Draw a section on the line AB (diagram IV.) Heights to distances as 6 to 1.—*Ib.*, *Sept.* 1894.

9. Number on the map (diagram V.) the contours from the lowest to the highest, and draw a section on a line TA. Heights to distances as 3 to 1; contours normal.

—*Ib.*, *March* 1895.

10. On a scale of 8 inches to 1 mile draw a section from right to left from the following data: Heights to distances as 6 to 1.

Assume the point A as 150 feet above sea level, and give the actual slopes between CD, GH, and HI.

From	To	V.I. 20 feet.	Horizontal distances in yards.
A	B	Level	150
B	C	Fall	200
C	D	"	140
D	E	Level	100
E	F	Rise	165
F	G	Level top of knoll	110
G	H	Fall	135
H	I	"	90

—*Ib.*, *Sept.* 1895.

11. In the sketch before you (diagram VI.) draw a section along the line AB, making the vertical scale six times the horizontal.

What is the amount expressed as a fraction of the steepest gradient on this line?—*Promotion, Lieutenants, May* 1892.

12. Draw a section on the line AB, assuming the scale of the plan to be 6 inches to 1 mile, and the contours at 20 feet V.I.

Vertical heights to be shown six times the horizontal scale (see diagram VII.)—*Promotion, Captains, May* 1893.

13. Make a section on the line CD of the sketch (diagram IX.) given you. The scale of the sketch is 2 inches to 1 mile. Heights to distances as 6 to 1.

—*Promotion, Lieutenants, Nov.* 1893.

14. Draw a section on AB (see diagram VIII.) Scale 2 inches to 1 mile; V.I. 50 feet; heights to distances as 6 to 1.
—*Promotion, Captains, Nov.* 1893.

15. Draw a section on the line CD (diagram II.) under the following conditions: Scale of the diagram 6 inches to 1 mile; contours normal; heights to distances as 6 to 1.
—*Admission Staff College, May* 1892.

16. Make a section of the ground shown on the accompanying diagram (diagram X.) on the line PQ. Vertical scale to be five times the horizontal.—*Ib., May* 1894.

17. A section is required on a certain line on a map, R.F. $\frac{1}{10560}$. Heights to distances as 8 to 1. The contours are at 25 feet V.I.

What is the distance of the section lines from one another?

18. A section is required on a certain line on a French map, R.F. $\frac{1}{10000}$, the V.I. being 10 mètres. Heights to distances as 10 to 1.

At what intervals should the section lines be drawn?

1 mètre = 39·37 inches.

19. The section lines on a section are drawn $\frac{2}{11}$ of an inch apart. The section is on a certain line on a plan, R.F. $\frac{1}{15840}$, with normal contours.

What is the exaggeration of heights to distances?

20. A section has been made on a certain contoured plan, V.I. 20 feet; heights to distances as 10 to 1. The section lines are ·3 inches apart.

What was the scale of the map?

21. On a certain line on a French map marked "R.F. $\frac{1}{10000}$, V.I. 10 mètres," a section has been drawn. There are 11 section lines (*i.e.*, 10 intervals), and the whole height of the section from the bottom line to the top measures 1·9685 inches.

What is the exaggeration of heights to distances?

22. On a French map a section has been made. Heights to distances as 10 to 1. The V.I. was 10 mètres, and the distance between the section lines is ·262 of an inch.

What is the R.F. of the map?

1 mètre = 39·37 inches.

23. The section lines on a section are ·164 inches apart. They represent the contours on a French map, R.F. $\frac{1}{80000}$, the vertical scale being $\frac{1}{12000}$.

What is the V.I.?

1 mètre = 39·37 inches.

24. Along a line AB on a contoured plan, R.F. $\frac{1}{15840}$, V.I. 25 feet, you measure the following slopes between contours starting from A, 2°, 3°, 4°, and 8° down, then $2\frac{1}{2}$° down for half a contour interval to a river, then $1\frac{1}{2}$° up for half a contour interval, then 1°, 6°, and 4° up to B.

Draw a section on AB. Heights to distances as 8 to 1. A is on contour 300 feet above datum.

25. Make a section and elevation (looking towards north-east) on the line GH (Plate XIV.) Heights to distances as 12 to 1.

26. Make a section and elevation (looking towards the west) on the line GM (Plate XIV.) Heights to distances as 9 to 1.

GROUP X.

FINDING THE NORMAL V.I. WHEN THE SCALE OF THE MAP IS GIVEN, AND *VICE VERSÂ*.

1. On examining the diagram (see diagram XI.) you will find a contour marked 64′ and another marked 48′, the diagram being contoured on the normal system.

What is the scale of the diagram?

—*Militia Competitive, March* 1891

2. What is the normal V.I. for a sketch having an R.F. of $\frac{1}{10430}$?

Supposing that the V.I. was directed to be 30 feet for a sketch drawn on a scale of $\frac{1}{10430}$, what would be the H.E. in yards for a slope of 5°?—*Promotion, Lieutenants, May* 1895.

3. What would the normal V.I. be for the following scales: 2 inches to 1 mile, 10 inches to 1 mile, $1\frac{1}{2}$ mile to 1 inch, 1100 yards to 1 inch, R.F. $\frac{1}{11880}$, R.F. $\frac{1}{18480}$, R.F. $\frac{1}{23760}$, R.F. $\frac{1}{3960}$?

4. What would the representative fractions of maps contoured on the normal system be when the vertical intervals were as follows: 15 feet, 25 feet, 100 feet, $17\frac{1}{2}$ feet, $27\frac{1}{2}$ feet?

5. Suppose French officers used a normal system of contouring similar to ours, but based on the convention that when a scale, R.F. $\frac{1}{20000}$, was used, the vertical intervals between the contours should be 10 mètres.

What would be the proper V.I. to use with the following scales: $\frac{1}{15000}$, $\frac{1}{8000}$, $\frac{1}{25000}$, $\frac{1}{50000}$?

GROUP XI.

MAGNETIC VARIATIONS.

1. If, having ascertained the true meridian, you find on taking its bearing with the prismatic compass that it is 344° 30′, what would the magnetic variation of your compass be, and would it be east or west of true north?

—*Militia Competitive, Sept.* 1883.

2. The declination of your compass is 18° E.; how would you lay down bearings obtained with it, assuming that the parallel lines on your paper represent true meridians?

—*Ib., March* 1885.

3. The diagram (see diagram XI.) being a portion of the Ordnance map, what is the bearing of G from B, and of B from C, taken with a prismatic compass having a declination of 17° 30′ W.?—*Ib.*, *March* 1891.

Note.—The examiner meant the candidates to take the side margins of the paper on which the map was printed as true N. and S., but as the map when reproduced for this book may not be in the same relative position to the margins in every copy, it will be more satisfactory if we suppose the point A is due north of the point G, and work the question on that assumption.

4. You wish to ascertain the variation of your compass. The site and occasion are suitable. A straight rod and plumb-line are at hand. How will you procure the required information?—*Ib.*, *March* 1894.

5. What is meant by the variation of the compass? In a locality where the variation of the compass is 16° W., two officers, A. and B., are making a compass sketch. A.'s compass has an error of 8° W., and B.'s compass an error of 8° E. At a certain spot A. finds the bearing of B. to be 28°. At the same time B. takes the bearing of A. What will it be by his compass?—*Ib.*, *March* 1896.

6. Before beginning a sketch with a compass, you wish to ascertain its variation. You find that the sun at a certain moment bears E.S.E., and at the same moment the angle between the sun and an object P measured round by south is 82°. If the bearing of P from where you are standing is 178°, what is the variation of the compass you are using?
—*Ib.*, *Sept.* 1896.

7. Taken with an instrument which has no magnetic variation, the bearing of an object is 187° 30′; the bearing of the same object from the same point taken with your prismatic compass is found to be 180°. What is the variation of your compass, and is such variation easterly or westerly?
—*Promotion*, *Captains*, *Nov.* 1891.

8. What do you understand by the "declination" of the compass? is it a constant quantity? If not, how does it vary? What is its amount at the present time in the south of England? Supposing you were quartered elsewhere, and did not know the amount of the declination at your new station, how would you proceed to ascertain it if no special instruments were available?

—*Promotion, Lieutenants, May* 1892.

9. What would be the bearing of the sun at noon, observed with a compass having a magnetic variation of 22° W.?

—*Ib., May* 1892.

10. What is the difference between a "magnetic bearing" and a "true bearing"? The true bearing of a line is 335°, the magnetic bearing of the same line is 352°. What is the variation of the compass? What would be the sun's bearing when on the meridian with the same compass?

—*Promotion, Captains, May* 1892.

11. How is the card of a prismatic compass graduated? The bearing of the sun at noon on the meridian of a place was found to be 162° 30′; what was the magnetic variation of the compass used?—*Ib., Nov.* 1892.

12. At 12 o'clock the true bearing of the sun is 3° west of south. At the same instant the compass bearing of the shadow of a stick placed vertically in the ground is found to be 12°. What is the magnetic variation of the compass used?—*Ib., Nov.* 1894.

13. How can you determine the variation of your compass without the aid of any instruments? Supposing you have found such variation to be 10° 30′ W., what would be the bearing (given by your compass) of the sun when on the meridian at noon?—*Admission Staff College, June* 1890.

14. In making a prismatic compass sketch, you assume that the magnetic variation of your compass is 18° W., and

you accordingly arrange the paper so that the margins shall run true north and south. After the sketch is finished you ascertain that the true bearing of a line PQ is 116°, whereas by your compass it is 98°. (*a*) What is the correct variation of the compass? (*b*) What is the east or west error, if any, in the direction of the margins of the paper?—*Ib.*, *May* 1894.

15. Explain the terms "magnetic dip" and "magnetic variation." How is the latter determined with sufficient accuracy for military purposes?—*Ib.*, *May* 1891.

16. What would be recorded as the magnetic variations of compasses from the following observations?—(*a*) The bearing of the pole-star when on the meridian being 345° 30′. (*b*) The bearing of the sun when on the meridian being 195° 30′. —*Ib.*, *August* 1895.

17. From a point A on the Ordnance map to a point B on the top edge of the map the bearing is 72°. The line AB makes an angle of 35° with the top edge of the map, A being south-west of B. What is the variation of the compass with which the observation was taken?

18. Wishing to ascertain the variation of a compass, I take the bearing to an object with another compass the variation of which I know to be 13° W. This bearing reads 75°. I then take the bearing of the object with the first compass, and find it reads 58°. What is the variation?

19. The bearing of the sun at noon, Greenwich time, is $163\frac{1}{2}$°. On that day Greenwich time was 10 minutes slow with regard to solar time. What was the variation of your compass?

20. At 10 A.M. the sun is observed to be vertically over an object which bears 169°. Give the variation of the compass used, supposing that on the day of observation the sun rose at 6 A.M. and set at 6 P.M.

21. At a certain time before, and the same lapse of time after, solar noon, the sun was observed to be vertically over two objects, the bearings of which were observed to be 152° and 222°. What was the variation of the compass used?

22. Wishing to find the variation of a compass "A," I take the bearing of an object with another compass "B," the variation of which I know to be 12° W. The bearing reads 5°. I then take the bearing of the same object with compass "A"; the reading is 355°. What is the variation of compass "A"?

23. What would be the bearing of the sun when on the meridian, if taken in the southern hemisphere with a compass the variation of which is 8° E.?

24. Suppose that the angular distance between the pole-star and the pole is $1\frac{1}{2}$°. I take the bearing of the pole-star at a time when "Zeta" of the Great Bear is east of the pole-star and in the same horizontal line with it. The compass reads $15\frac{1}{2}$°. What is its variation?

25. At 1 P.M. by my watch I take the bearing of the sun; it is 202°. My compass has a variation of 15° W. At 2 o'clock by my watch another observer takes the bearing of the shadow of a vertical object with his compass, and reads 30°. What is the variation of the compass with which the second observation was taken?

GROUP XII.

CALCULATION OF HEIGHTS AND DISTANCES.

1. The gradient of a railway being $\frac{1}{80}$, how many feet does it rise in a mile and a half?

A river rises 550 feet above the level of the sea, and falls at a uniform gradient of $\frac{1}{200}$ to the sea. What is the distance from the source of the river to its junction with the sea?

—*Militia Competitive, March* 1892.

2. Give the H.E. in yards for 20-feet contours at 1° and 7° of slope.—*Ib., March* 1893.

3. A railway runs through the points X Z Y (see diagram XV.) Assuming the level of the railway at X to be 185 feet, and that the gradient from X to Z is uniformly $\frac{1}{90}$ down and from Z to Y uniformly $\frac{1}{60}$ up, will the line be in cutting or embankment at Y, and to what depth or height?

—*Ib., March* 1896.

For the purposes of this question take the scale of the map to be 6 inches to 1 mile, and let the contours be at 25 feet intervals.

4. From a point A, which is 750 feet high, the distances to B and C are 191 and 573 yards, and the vertical angles are $-4°$ and $+7°$ respectively. What are the heights of B and C?—*Promotion, Captains, May* 1892.

5. From the summit of a tower, and from a window in the tower 25 feet below the summit, the angles of depression to an object are found to be 21° and 10°. At what distance is the object from the tower, and what is the height of the tower?—*Promotion, Lieutenants, Nov.* 1892.

6. The height of a certain point on a sketch is known to be 140 feet above datum. From another position on the sketch the angle of elevation to the known point is found to

be $2\frac{1}{2}°$; the distance between the points is exactly half a mile. What is the height of the second position above datum? The height of the eye may be taken equal to 5 feet.

—*Promotion, Captains, Nov.* 1892.

7. What is the meaning of "a gradient"?

If you are standing on the ground at a point X, of which you know the level to be 180 feet, and found the angle of elevation to another point Y, of which you know the level to be 270 feet, to be $2\frac{1}{2}°$, what is the gradient from X to Y? What is the distance in plan between X and Y?

—*Ib., Nov.* 1894.

8. From the top of a hill marked 750 feet you can just see the weathercock on a church spire distant 860 yards. Half-way between you and the spire is another hill marked 675 feet. The ground on which the church stands is marked 500 feet. How high is the church spire?

—*Admission Staff College, June* 1890.

9. The angle of elevation from a col C to the crest of a hill A is 8°, and the distance CA is 150 yards. From the same col an angle of elevation to the top of a knoll B is 6°, the distance CB being 88 yards. What is the command of A over B?—*Ib., May* 1892.

10. It is required to ascertain the distance from bank to bank of a river, the banks of which cannot be reached for purposes of direct measurement. It is, however, possible to see them from the top of a tower 300 feet high, from which the angle of depression to the near bank is 7° and to the farther bank 5°. The ground from the foot of the tower falls uniformly to the near bank at 2°. What is the distance from bank to bank?—*Ib., May* 1894.

GROUP XIII.

DETERMINATION OF HEIGHTS AND DISTANCES BY PLOTTING TO SCALE.

1. From the top of a house, and from a window 30 feet below the top, the angles of depression to an object are observed to be 21° and 10° respectively. What is the distance of the object from the house, and what is the height of the house? Scale $\frac{1}{500}$.—*Militia Competitive, March* 1884.

2. A and B are stations on your sketch 10 chains apart, and B bears 245° from A. C is another station whence A bears 50° and B 350°. Find the distances CA and CB in feet, and the values of the angles A, B, and C. Scale $\frac{1}{2400}$.
—*Ib., March* 1885.

3. Three stations, A, B, C, are so situated that A and B are 1200, B and C 1000, and A and C 1425 yards apart. C is observed from A to make with the magnetic meridian an angle of 83°, and B lies north of AC. From a point D the bearings of A and C are observed to be 325° and 50° respectively. Ascertain the distance of D from B, and the angle which D B makes with the magnetic meridian. Scale 300 yards to 1 inch.—*Ib., Sept.* 1895.

4. You stand on a hill 200 feet high, from which you find that the angles of depression to the banks of a river are 40° and 20°. What is the breadth of the river? Scale 100 feet to 1 inch.

5. In traversing you find the bearings of two known points from a station to be respectively 192° and 97°: assuming that the second point is 1000 yards N.E. of the first point, what would be the length of the shortest offset you could take from the station in order to align yourself between the two points?—*Promotion, Captains, Nov.* 1894.

6. Plot the following on a scale of 12 inches to 1 mile, and give the length and bearing of HM. AB = 460 yards:—

From A, B bears 74° and C 118°
" B, C " 202° " D 135°
" D, C " 255°
" F, A " 155° " B 100°
" D, H " 20° Distance 225 yards.

The point M lies to the west of the line FA; it is 325 yards from F and 275 yards from A.

GROUP XIV.

DEFINITIONS.

1. Explain as concisely as possible the following terms: "watershed," "col," "underfeature," "contour."
—*Militia Competitive, Sept.* 1886.

2. Define the following terms: "contour," "gradient," "slope," "horizontal equivalent."
How are the second and third of these usually expressed?
—*Ib., March* 1893.

3. Define the following terms used in military topography: "zero line," "back angle traversing," "meridian," "saddle," "col," and "datum line."—*Promotion, Captains, May* 1893.

4. Define the following terms used in military topography: "bearing," "plotting," "traverse," "forward angle," "back angle," "offset," "contour," "horizontal equivalent," "meridian," "magnetic meridian," "saddle," "watershed."
—*Promotion, Lieutenants, May* 1894.

5. Explain the terms "magnetic dip" and "magnetic variation."
How is the latter determined with sufficient accuracy for military purposes?—*Admission Staff College, May* 1891.

GROUP XV.

INSTRUMENTS.

1. Prismatic compass.

(*a*) How is the card graduated?

(*b*) At what point does the graduation of the card commence, and for what reason?

(*c*) In what direction is the graduation of the card read?

(*d*) Why is it necessary that the magnetic variation of every compass should be known?

(*e*) Why is it necessary that the whole of a sketch should be executed with one and the same compass?

—*Militia Competitive, March* 1892.

2. The instruments for the most part used by regimental officers in military sketching are the prismatic compass and the plane-table. Summarise the advantages and defects of each.—*Ib., March* 1894.

3. How is the card of a prismatic compass graduated?

—*Promotion, Captains, Nov.* 1892.

4. Contrast the relative values of the prismatic compass and plane-table as field-sketching instruments, and show in what way the angular measurements taken with the former are more liable to error than those made with the latter.

—*Ib., May* 1893.

5. What is meant by the index error of a clinometer? How is the amount of index error ascertained? Give an example.—*Ib., Nov.* 1893.

6. How do you ascertain whether a Watkin range-finder is in adjustment? Explain how the instrument can be used for measuring small angles.

—*Admission Staff College, May* 1891.

GROUP XVI.

CONVENTIONAL SIGNS.

1. Draw as neatly as you can, on a scale of 6 inches to 1 mile, the conventional signs for—(*a*) a marsh, (*b*) a metalled road partly in cutting and partly on embankment, (*c*) a double line of railway.—*Militia Competitive*, *Sept.* 1886.

2. An observer at A (see diagram XIII.) finds that the height of the sun above the horizon was precisely the same when it was over B and C. Draw the magnetic and true meridian on the diagram in accordance with the conventional signs, the variation being taken as at present in London.

—*Ib.*, *Sept.* 1891.

3. Figure at some convenient place outside the margin of the map (diagram XIV.) the true and magnetic north points for the map with the usual conventional signs, assuming that the magnetic variation of your compass was 17° E. Assume that the vertical marginal lines of your map run magnetic north and south.—*Ib.*, *March* 1893.

4. The bearing of the sun at noon reads 197° 30′. Draw the true and magnetic meridians.—*Ib.*, *March* 1894.

5. Show on the diagram (diagram IV.), by the usual conventional signs, a battalion of six companies 500 strong in column near D and in line near S, a battery for 6 guns near M, a double line of railroad with cutting and embankment from T to F.—*Ib.*, *Sept.* 1894.

6. Draw neatly on the map (diagram V.) the true and magnetic north, the variation being 15° W., and the magnetic bearing of A from B being 330°; a fir-wood on Farley Hill; a village near the junction of the streams; a road from X to A enclosed as far as bridge P, with cultivated fields on either side between P and A; a marsh near K.—*Ib.*, *March* 1895.

7. Represent by means of a few contours at 20 feet V.I. a tract of hilly country about a half square mile in extent, on a scale of $\frac{1}{10560}$, containing the following features, one or more of each: A valley, a col, a ridge, a spur, an under-feature, and a stream flowing in a south-easterly direction into the sea.

General direction of the coast-line east and west. Cliffs 40 feet high at the eastern end of it.

—*Promotion*, *Captains*, *May* 1892.

8. Draw neatly with pen and ink the following conventional signs suitable to a scale of 6 inches to 1 mile: A village, an orchard, a hop-field, a double line of railway passing through a cutting and tunnel and along an embankment, a rocky coast-line, and a marsh.—*Ib.*, *Nov.* 1892.

9. In a survey executed in Bengal the magnetic variation was found to be 15°, and in one executed in Austria the magnetic variation was found to be 6° 45′. Draw the true and magnetic north in both the above cases in accordance with that portion of the conventional signs.

—*Promotion*, *Lieutenants*, *May* 1893.

10. Draw a plan representing half a square mile of country on a scale of 6 inches to 1 mile, and introduce as many conventional signs as possible, having due regard to probability. Put in contours in continuous red lines at 20 feet V.I., and show the direction of true and magnetic north, the variation being $4\frac{1}{2}$° E.—*Promotion*, *Captains*, *May* 1893.

11. Draw neatly with pencil or ink the conventional signs for—Sentry; vedette; single line of railway with embankment, cutting, and tunnel; telegraph; clearances and demolitions; true and magnetic north; entanglements or abatis.—*Promotion*, *Lieutenants*, *Nov.* 1893.

12. In a square of 6 inches side, and on a scale of $\frac{1}{10560}$, draw a contoured sketch of an imaginary country. The

following particulars are to be shown: Watershed; saddle; one or more features; knoll; cliff; river; iron bridge; ford; ferry; single line of railway with tunnel, embankment, cutting, telegraph line; metalled road.

Give the authorised conventional signs for the objects here referred to, if you do not make the imaginary sketch.

—*Ib., Nov.* 1894.

13. Draw an imaginary piece of ground about a square mile in area, and show any twelve conventional signs you can remember, other than bodies of troops. State on the sketch what your different signs represent. Contours normal. Scale (about) 4 inches to 1 mile.

Marks will be awarded for neatness of execution.

—*Promotion, Captains, Nov.* 1894.

14. Give the conventional signs for—Clearances or demolitions, entanglements or abatis, intrenchment, rifle-pits, battery, site of battle, picquet, support, sentry, vedette.

—*Promotion, Lieutenants, May* 1895.

15. Draw a plan of an imaginary piece of contoured country showing a village, a church, cultivated fields, an open common with a highroad across it, a double line of railway over small stream, embankment, cutting, and tunnel.

—*Admission Staff College, May* 1891.

16. An observer at *e* (see diagram II.) finds that the height of the sun above the horizon was precisely the same when it was over the churches at A and B. Draw the magnetic and true meridians in accordance with the conventional signs, the variation being taken as that which now obtains in London.

—*Ib., May* 1892.

17. Draw in the usual colours an imaginary piece of ground about 2 square miles in area, showing contours on the normal scale and the following features, &c.—viz.: Spurs, valleys, col, tidal river, sea-shore with cliffs and anchorage, metalled

road, track with no boundary, fences, hedges, marsh, village with a church, woods and orchards, railway with a cutting and embankment, telegraph line. Specify which is which. Scale 3 inches to 1 mile.—*Ib.*, *May* 1894.

GROUP XVII.

PLOTTING FROM FIELD-BOOKS, FIELD-NOTES, ETC.

1. Plot the following field-notes of a road traverse on a scale of 12 inches to 1 mile, and state in figures the length and bearing of the closing line DA (see p. 45).

—*Militia Competitive*, *March* 1884.

2. Plot the following bearings and distances taken along a road—scale $\frac{1}{5280}$:—

A to B,	bearing	320°,	distance	340 yards.
B to C,	"	288°,	"	110 "
C to D,	"	332°,	"	300 "
D to E,	"	30°,	"	250 "

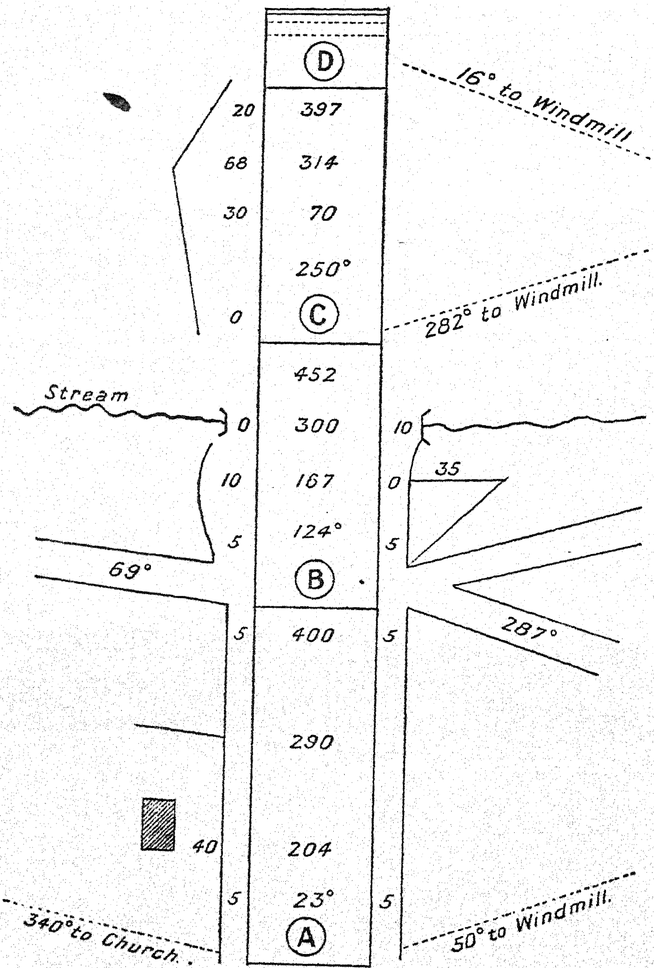
From A a spire bears 31°, and from E 109°, while from an unknown point X the bearing of A is 100°, and of E 11°. Find and write down the distance between X and the spire, as also its bearing from the latter.—*Ib.*, *Sept.* 1886.

3. Plot the following bearings of a triangulation executed with a prismatic compass :—

At A,	B	bears	48°	At B,	E	bears	108°
"	E	"	70° 30′	"	G	"	116° 30′
"	G	"	83°	"	F	"	189°
"	D	"	106° 15′	"	D	"	156°
"	F	"	131° 30′	"	A	"	228°
"	C	"	321° 30′	"	C	"	266°
"	H	"	10°	"	H	"	273° 15′

Base AB = 650 yards. Scale 8 inches to 1 mile.

—*Ib.*, *March* 1887.



D
16° to Windmill
20
397
68
314
30
70
250°
0
C
282° to Windmill.
452
Stream
0
300
10
10
167
0
35
5
124°
5
69°
B
5
400
5
287°
290
40
204
5
23°
5
340° to Church.
A
50° to Windmill.

4. Plot the following field-notes of a traverse made round a lake with a prismatic compass, and give in figures the length and bearing of the closing station GA :—

From A to B,	bearing	48° 30′,	distance 230 yards.
" B to C,	"	53°,	" 190 "
" C to D,	"	120° 15′,	" 275 "
" D to E,	"	186° 30′,	" 255 "
" E to F,	"	254°,	" 320 "
" F to G,	"	19° 15′,	" 130 "

Scale 12 inches to 1 mile.

—*Ib.*, *Sept.* 1888.

5. Lay down the following intersection of stations on a scale of 8 inches to a mile, and give the R.F. Base AB = 910 yards :—

At A, bearing of B = 90°	At B, bearing of A = 270°
" C = 10°	" C = 312°
" D = $45\frac{1}{2}$°	" D = 343°
" E = $62\frac{1}{2}$°	" E = 9°
" F = $160\frac{1}{4}$°	" F = 210°
" G = 190°	" G = $245\frac{1}{2}$°

Resected at X, bearing of F = 234°
" " B = 323°

Show the true and magnetic meridians on your sketch, assuming that your compass has a variation of 5° W.

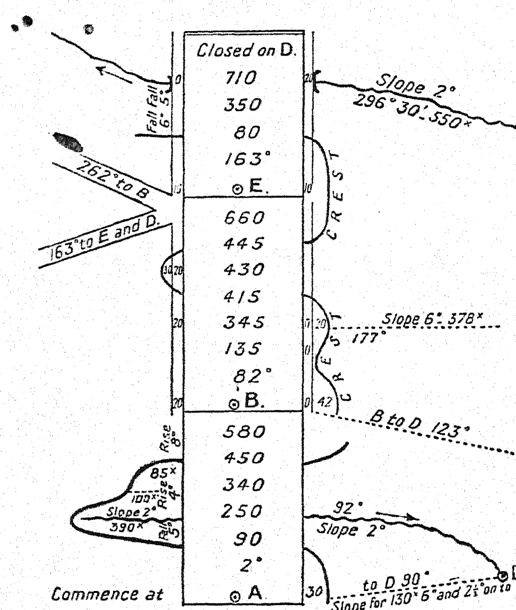
—*Ib.*, *Sept.* 1892.

6. Plot to a scale of 6 inches to 1 mile the following portion of a field-book, and complete the contours. All measurements in yards; V.I. normal. Draw the true and magnetic north, the variation being 5° E.

—*Ib.*, *March* 1892.

Note.—When working this question make two alterations—viz.: the angle from A to D should be 90° 30′, and from B to D should be 124° 15′, and not 90° and 123° as stated.

(See diagram on p. 47.)



7. Plot the accompanying field-book notes of a road traverse, and show the positions of two conspicuous points A and B, the bearings of which are as follows:—

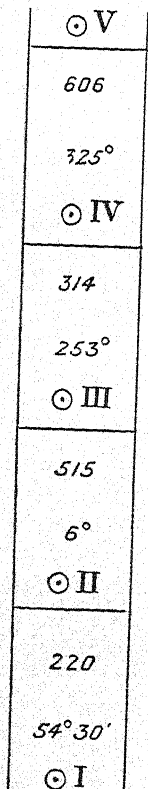
From I.—A bears 300°	From III.—A bears 225°
" II.—B " 360°	" V.—B " 80°

Scale 7 inches = 1 mile.

Draw the scale to show yards, and give the R.F. Ink in or darken the line of road, leaving the rest of the work in light pencil (see diagram, p. 48).—*Ib.*, *March* 1893.

8. From a point X the bearing of a point Y, distant 3 furlongs, is 160°. From a point Z the bearing of X is 295°, and of Y 230°. Show the position of Z. The line XY subtends at a point W, on the side opposite to Z, an angle of 60°, and WX, WY, each equal 660 yards. Give the bearing and distance of Z from W. Scale $\frac{1}{7920}$.—*Ib.*, *Sept.* 1894.

9. At a point A the bearing of a base AB is 90°, AB = 900 yards. A hill C bears 150° from A and 210° from B. The angle of elevation from A to C is 10°, and from A to B 3°. What is the height of C above A and B?—*Ib., Sept.* 1894.

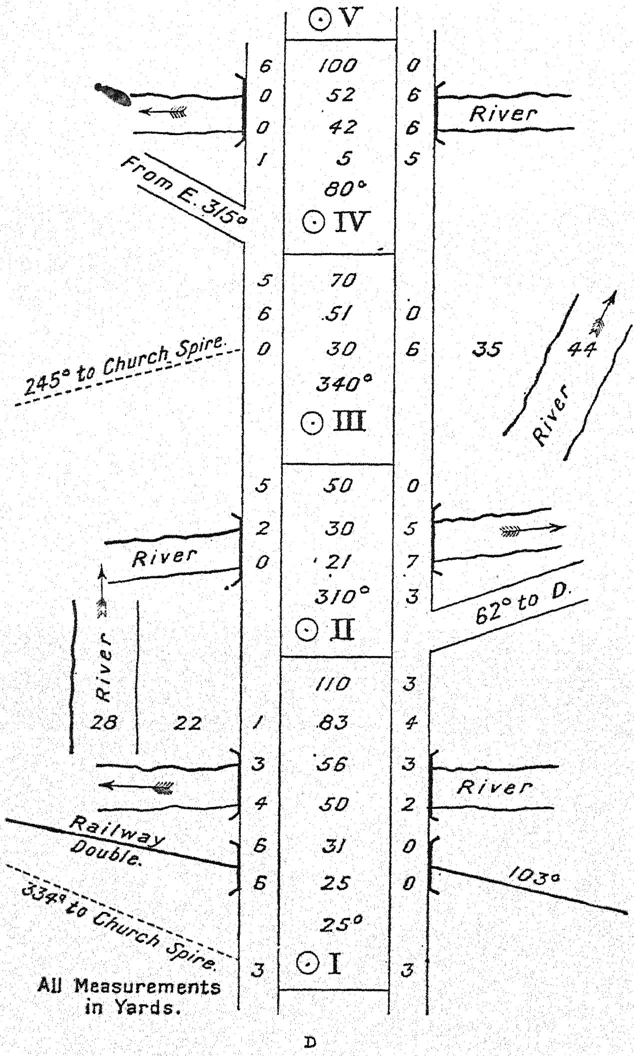


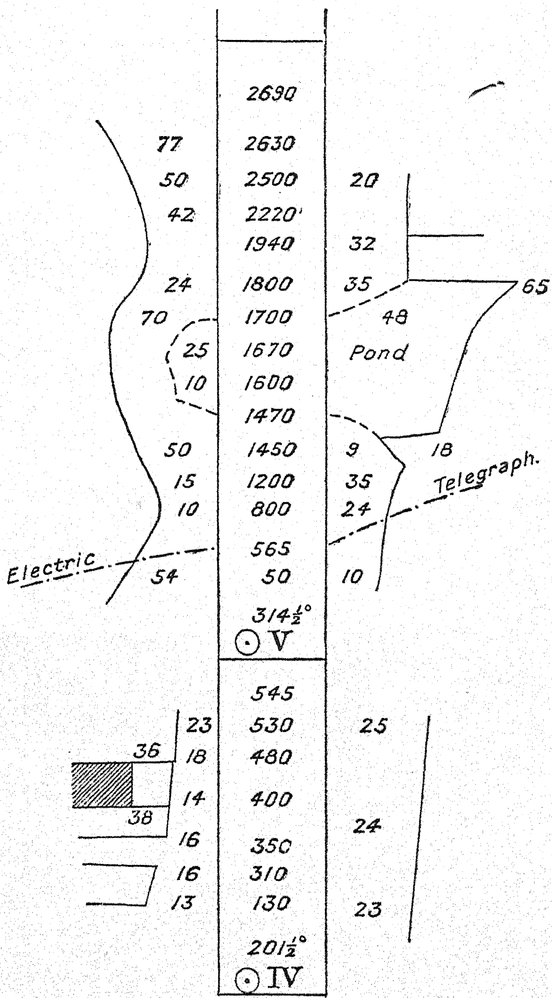
10. Working on the ground with a compass, the variation of which is 20° E., you want to lay off lines making angles of 85° and 55° respectively with another line, the *true* bearing of which is known to be 135°. If both these angles fall to the westward, what are the respective magnetic bearings of the lines as shown by your compass?
—*Ib., Sept.* 1895.

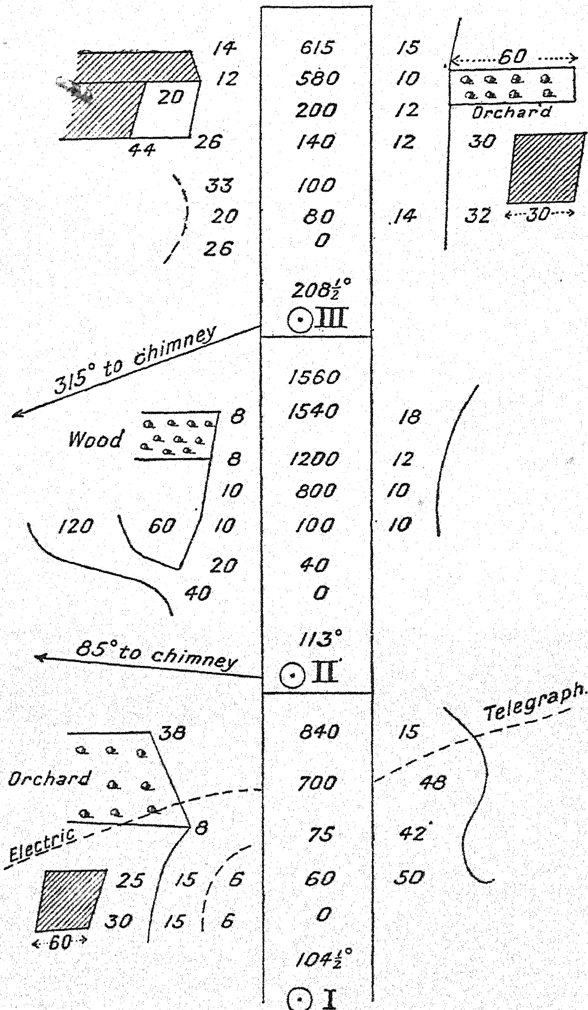
11. Plot neatly, in pen or pencil, using the usual conventional signs, the following extract from a field-book. Scale $\frac{1}{1440}$ (see p. 49).
—*Ib., March* 1895.

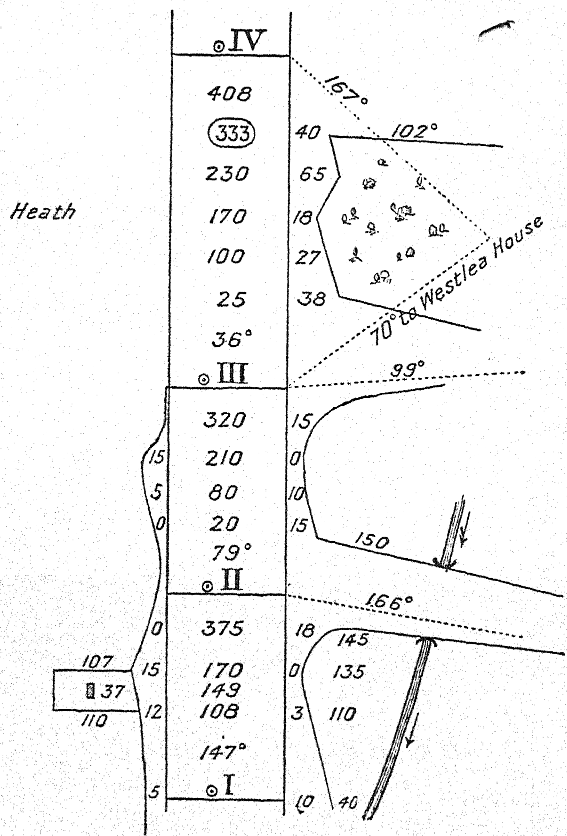
12. All measurements are given in yards. Meridians to be arranged so that first forward angle is in direction parallel to the side margin of the paper. North point to be marked. To be plotted on scale of 6 inches = 1 mile. Take ⊙ 1 near the left-hand bottom corner of the paper, about $1\frac{1}{2}$ inch from the lower edge and 2 inches from the left edge (see pp. 50, 51).
—*Ib., Sept.* 1896.

13. To a scale of $\frac{1}{5280}$ plot the portion of a field-book given on p. 52. Ascertain and write down the distance in a straight line from ⊙ IV. to ⊙ I., and the bearing of ⊙ I. from ⊙ IV.
—*Promotion, Captains, Nov.* 1891.


V
6 100 0
0 52 6
0 42 6
1 5 5
80°
River
From E. 315°
IV
5 70
6 51 0
0 30 6
340°
245° to Church Spire.
35 44
River
III
5 50 0
2 30 5
0 21 7
310° 3
River
62° to D.
II
110 3
1 83 4
3 56 3
4 50 2
6 31 0
6 25 0
25°
River
28 22
River
Railway Double.
103°
334° to Church Spire.
3 I 3
All Measurements in Yards.
D


2690
77
2630
50
2500
20
42
2220'
1940
32
24
1800
35
65
70
1700
48
25
1670
Pond
10
1600
1470
50
1450
9
18
15
1200
35
Telegraph.
10
800
24
Electric
565
54
50
10
$314\frac{1}{2}°$
⊙ V
545
23
530
25
36
18
480
14
400
38
24
16
350
16
310
13
130
23
$201\frac{1}{2}°$
⊙ IV


14
615
15
60
12
580
10
20
200
12
Orchard
44
26
140
12
30
33
100
20
80
14
32
30
26
0
208½°
III
315° to chimney
1560
8
1540
18
Wood
8
1200
12
10
800
10
120
60
10
100
10
20
40
40
0
113°
85° to chimney
II
Telegraph.
38
840
15
Orchard
700
48
8
75
42
Electric
25
15
6
60
50
30
15
6
0
60
104½°
I


IV
408
333
230
170
100
25
36°
III
320
210
80
20
79°
II
375
170
149
108
147°
I
Heath
167°
102°
40
65
18
27
38
70° to Westlea House
99°
15
0
10
15
150
15
5
0
166°
18
145
0
135
3
110
10
40
107
37
110
15
12
5

14. Plot the following. Scale 6 inches to the mile. Base AB, length 1000 yards, bearing 180°.

At A, bearing of C=131°	At B, bearing of D=325°
" D=257°	" C= 76°

Resected at E, bearing of A=322½°
" " D=295°

What is the distance of E from C? Do you consider this a satisfactory method of determining the position of E? Give reasons for your answer.—*Promotion, Lieutenants, May* 1892.

15. Plot the following to a scale of 12 inches to 1 mile :—

Bearing of B from A is 125°
" C " A " 81°
" A " D " 344°
" D " B " 246°
" B " C " 157°
A is 625 yards from B.

Join CD by a chain-dotted line, and state its length in yards.—*Promotion, Captains, May* 1892.

16. Lay down the following to a scale of $\frac{1}{10560}$. Base AB=520× :—

Bearing A to B= 60°	Bearing B to E=190° 30′
" A " C= 10°	" B " F=149° 30′
" A " D= 43°	" B from G=269°
" A " E=136° 30′	" F " G=210°
" A " F=101°	" F " H=360°
" A " K=174°	" E " H=297° 30′
" B " C=283° 30′	" K " H=269° 30′
" B " D= 4°	

(*a*) If in the foregoing you observe any objectionable intersections, state which they are, and why you consider them objectionable.

(*b*) How could you test the accuracy of the intersection of such points as may seem to be objectionable, and so remedy the defects?

(*c*) Owing to the configuration of the ground, it was necessary, in the first instance, to select AB as a base, but as an

extension of the sketch is required, more particularly towards the east and west, what two points, already fixed, would you select for the ends of a supplementary base, presuming, in this case, that all points are mutually visible?

(*d*) Give the bearing of the supplementary base from either end of it.

(*e*) At about 30$^\times$ from A the ground falls rapidly towards K, and renders K invisible from A: how would you obtain the bearing of K from A?

(*f*) What steps would you take the better to ensure the accuracy of the points G and K?

—*Promotion, Lieutenants, Nov.* 1892.

17. Plot on a scale of 6″ to 1 mile the position of the point D from the following data: The bearing of B from A is 72°, and the distance 550 yards. C bears 130° from B, and is 660 yards distant. At D, A bears 310°, B is due magnetic north, and C bears 69°. What is the distance from D to A?

—*Promotion, Captains, Nov.* 1892.

Read the note to the answer before plotting this question.

18. Lay down the following intersections of stations, AB base = 995 yards:—

Bearing of B from A 355°

At A, bearing of D = 28°	At B, bearing of D = 133°
" E = 312½°	" E = 242½°
" F = 263°	" F = 223°

Resect C, bearing of B = 236½°
" " D = 191°

Scale 6 inches to a mile.

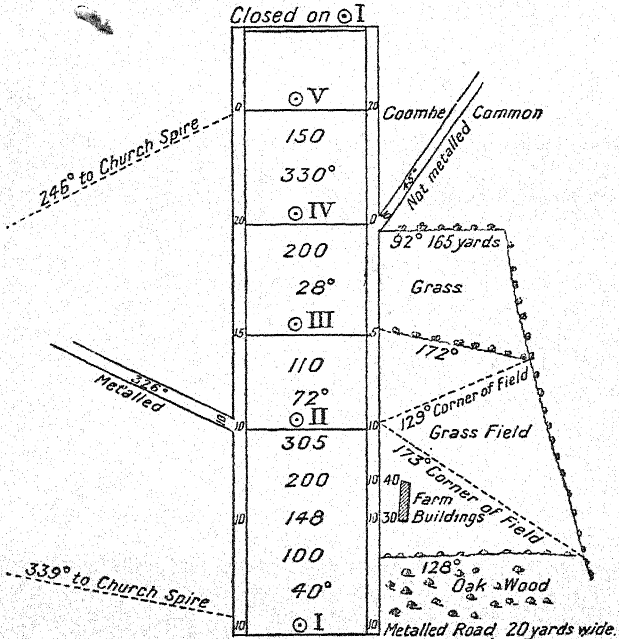
Show the true and magnetic north, assuming the variation as 13° E.—*Ib., Nov.* 1893.

19. Portion a field-book to be plotted with the greatest care and neatness to scale, R.F. $\frac{1}{5280}$. The closing bearing and distance from ⊙ V. to ⊙ I. must be given (see p. 55).

—*Promotion, Lieutenants, May* 1893.

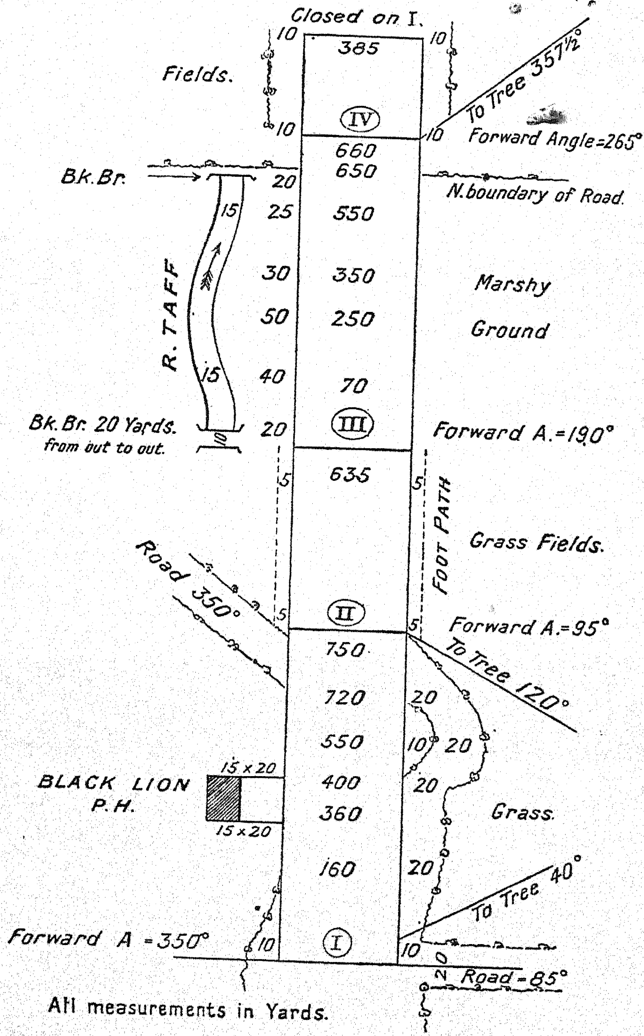
20. Plot the accompanying extract from a field-book neatly, on a scale of 12 inches to 1 mile (see p. 56).

—*Promotion, Captains, May* 1893.



21. Plot the following intersections of stations. Scale $\frac{1}{10560}$. AB is the base, and distance of A to B is 850 yards:—

A to B = 180°	B to D = 64°
" K = 45°	" E = 278°
" D = 125° 30′	" C = 318°
" E = 215°	H to D = 158° 30′
" C = 256°	" C = 234°
B to A = 360°	L to H = 77°
" K = 19°	" E = 155° 30′



All measurements in Yards.

(*a*) What points in this work are found by resection (or interpolation)?

(*b*) Do you take exception to any station fixed by these observations? If so, how will you check the position of the station? All the stations can be seen from each other with this exception: K cannot be seen from D or L.

(*c*) What is the distance of E from H, and of L from D?

—*Promotion, Lieutenants, Nov.* 1893.

22. Plot the following. Scale $\frac{1}{10560}$:—

At A, bearing of C = 104°	At B, bearing of Z = 97°
" B = 153°	At X, bearing of H = 41°
" D = 211°	" D = 151°
" H = 324°	" A = 89°
At B, bearing of A = ~~233~~°	At Y, bearing of H = 273°
" C = 41½°	" C = 180°
" D = 269°	At Z, bearing of C = 336°

Distance from A to B 740 yards.

—*Ib., May* 1894.

23. On a scale of $\frac{1}{10560}$ plot the following entries taken from a field-book, also give the bearing of A from E, and the distance between A and E. The entries are—

A to B,	bearing	25°,	distance	1000 yards.
B to C,	"	45°,	"	850 "
C to D,	"	360°,	"	500 "
D to E,	"	295°,	"	715 "

—*Ib., Nov.* 1894.

24. Plot the following intersection of stations. Scale $\frac{1}{10560}$. The long side of the paper is to be taken as the meridian. The point B is about 3 inches from the bottom edge and in the central line of the page. Base AB = 970 yards:—

From	B	the bearing of	A	is	318½°
"	B	"	D	"	268°
"	B	"	C	"	12°
"	A	"	C	"	88°

From A	the bearing of	D	is 192°
" D	"	E	" 358°
" D	"	G	" 98°
" C	"	E	" 289°
" C	"	G	" 174°
" F	"	E	" 267°
" F	"	G	" 187°

What is the distance in yards from D to F?

—*Ib.*, *May* 1895.

25. Plot the following intersection of stations on a scale of 6 inches to 1 mile.

N.B.—The station "A" may be placed about $2\frac{1}{2}$ inches from the top edge, and $2\frac{1}{2}$ inches from the right or east edge, of your paper.

The distance from A to B is 900 yards. The angles observed with the prismatic compass are—

From A to B = 213°	From B to A = 33°
" C = 260°	" C = 325°
" D = 155°	" D = 95°
" E = 238°	" E = 269°

From X to C the bearing is 346°
" X to D " 60°

In the above is there any intersection to which objection can be taken? If so, point it out, and show how the accuracy of this intersection may be checked.

Give the distance in yards from A to X and E to D.

—*Ib.*, *November* 1895.

26. A, B, and C, are three factory chimneys, A being 3 miles and C 4 miles distant from B, which bears 72° and $306\frac{1}{2}$° respectively from A and C. From a station X, C bears $28\frac{1}{4}$°, B 351°, and a church spire Z 254°. From a second station Y, B bears $21\frac{1}{2}$°, A $341\frac{1}{2}$°, and the spire Z 171°. Find by construction the position of Z, and the bearing and distance of X from Y.—*Admission Staff College, June* 1885.

27. Plot the following traverse. Scale 6 inches to a mile:—

A to B,	bearing	31°,	distance	990	yards.
B " C,	"	313°,	"	915	"
C " D,	"	338°,	"	530	"
D " E,	"	20°,	"	850	"

What is the bearing and distance from A to E?

—*Ib.*, *May* 1891.

28. Plot the following bearings and distances on a scale $\frac{1}{5280}$:—

A to B,	bearing	10° 30′,	distance	210	yards.
B " C,	"	125°,	"	250	"
C " D,	"	85°,	"	215	"
D " E,	"	180°,	"	235	"
E " F,	"	235°,	"	?	"
F " G,	"	275°,	"	195	"

On reaching F the sketcher finds he has lost count, but can see A, on which he takes a bearing of 330°. Explain how F can be fixed, and find bearing and distance of GA.

—*Ib.*, *June* 1889.

29. Plot in the following triangulation—scale 6 inches to 1 mile—angles observed from A:—

E=20° 30′	C=129°	K=175°	H=328°
D=97°	B=161°	F=200°	

The distance of A to B=690 yards. Angles observed from B:—

E= 3°	D= 53° 30′	G=289°	A=341°
C=27° 30′	F=260°	K=325°	

Bearing of A from X, 97°; bearing of F from X, 146°. Angles observed from X:—

H=29° 30′	G=227°

Is there any intersection to which you take exception? If so, how would you check it?—*Ib.*, *May* 1893.

Note.—As G is about 1200 yards west of A, and D is about 950 yards east of A, take care that you have sufficient space on each side of the point A to get G and D in.

30. Lay down the following intersection of stations on a

scale of 4 inches to 1 mile. Base AB = 1100 yards (to be shown about the centre of your paper) :—

At A, bearing of	B = 180°		At B, bearing of	D = 63°
" A, "	D = 120°		" B, "	E = [illegible]5°
" A, "	E = 216½°		" B, "	C = 305°
" A, "	C = 249°		" B, "	K = 342½°
" A, "	K = 325°		" C, "	G = 51½°
" D, "	G = 344°		" C, "	F = 146°
" D, "	F = 220°		" L, "	G = 82°
			" L, "	E = 162°

What is the check bearing of L from D, and the distance DL?

State if any of the above stations are badly fixed, giving the reasons for your opinion.—*Ib.*, *August* 1895.

GROUP XVIII.

KEEPING FIELD-BOOKS.

1. Show in field-book form all the entries you would make in traversing with a prismatic compass from station I. to station IV. (see diagram XIII.) The side margins of the diagram are to be considered as true meridians, and the magnetic variation as 18° E. Scale of the diagram 4 inches to 1 mile.—*Militia Competitive*, *Sept.* 1891.

2. Show the page of a field-book with all the necessary entries of a prismatic compass traverse of the roads *a b c d e a* (see diagram I.) The side margins of the diagram are to be considered as true north and south lines, and the magnetic variation as 10° W. Scale of the diagram $\frac{1}{15840}$. Contours at 15 feet V.I.—*Ib.*, *Sept.* 1893.

3. Enter as in a field-book, ruling the necessary lines on your paper, all the observations, measurements, &c., you

would make in traversing with a compass the road CDEF (see diagram IV.)—*Ib.*, *Sept.* 1894.

4. Explain briefly the method of conducting a traverse survey by means of a prismatic compass and field-book, and give an illustration of the entries which would be made in the latter on the assumption that you are traversing along a road.—*Promotion*, *Captains*, *May* 1892.

5. Explain clearly how to traverse with a field-book.
—*Promotion*, *Lieutenants*, *Nov.* 1893.

6. In the pages of a field-book, what entries are made in the "chain column" and what entries are in the "offset column"?—*Ib.*, *May* 1895.

7. To show your knowledge of keeping a field-book, rule the requisite lines on your paper, and enter the following particulars as if in a field-book:—

At the station at which the traverse commences the forward angle is 30°. The traverse is along a road, the width of which is 5 yards on either side of the traverse line, and the road is hedged in.

At this station the bearing of a country house "A" is 80°.

At 200 yards from the first station is a lodge gate and an avenue leading to house "A."

At 300 yards from the first station is the main road to the market town of B, the bearing of which road is 270°.

At 500 yards from the first station the traverse crosses the Great Northern Railway (double line, telegraph, level crossing), the bearing of the railway reads 100°.

The railway station is here on the east side, and it is noted that the width of the road is 20 yards, and that it is wholly to the west side of the traverse line.

The first line ends at the railway station. The bearing of the country house "A" from here reads 145°. The forward angle is also noted as 65°.—*Promotion*, *Captains*, *Nov.* 1895.

8. Show the page of a field-book with all the necessary entries of a prismatic compass traverse of the roads *c d e f c* (see diagram II.) The side margins of the diagram are to be considered as true meridians, and the magnetic variations as 10° W. Scale of the diagram $\frac{1}{10560}$; contours normal.
Admission Staff College, May 1892.

9. Illustrate how a field-book is kept, and plot the entries therein made on a scale of 6 inches to 1 mile. The entries are to be generally on the following lines: the exact details are left to your discretion :—

A road winding somewhat N.E., N., N.W., for a part of its way it is shut in by hedges and then without enclosure. The country passed through is in places cultivated and enclosed and in parts open moorland. A river is crossed where there is a ford and ferry; the approach to the river for 500 yards is along an embankment. A double line of railway and a line of telegraph follow the left bank of the river on the north side of the river, and cross the road by an open crossing.

From the first bend in the road is a highway leading to a town B 5 miles off, east. Here also to the west, some distance from the road traversed, lies a large factory. There is a village where the road to B branches off. The road traversed passes through a pine-wood for a short distance after the village is left.—*Ib., May* 1893.

GROUP XIX.

TRAVERSING.

1. Traversing with a plane-table through a wooded intricate country, the direction of the road constantly changing. Would you prefer working by the back-station or by the compass, as most likely to give you accurate results? Give your reasons.—*Promotion, Captains, May* 1894.

2. Explain traversing with the plane-table ; give a sketch showing three stations. What are the advantages of the plane-table ?—*Admission Staff College, May* 1891.

GROUP XX.

SELECTION OF BASE AND INTERSECTION OF STATIONS.

1. Draw a diagram of a triangulation suitable for a military sketch of 10 square miles of country to be laid down on a scale of 4 inches to 1 mile. Point out why in this question the extent of ground embraced is mentioned, also why the scale on which the work is to be laid down is made a matter of importance.—*Militia Competitive, Sept.* 1891.

2. Show on the diagram (diagram IV.) the triangulation you would adopt for a survey of the ground it represents. Give the magnetic bearings of R from N. and S., and show how you would fix the position of the bridge by resection.—*Ib., Sept.* 1894.

3. Show on the map (diagram V.) the base you would select and the triangulation you would adopt for an accurate survey of the ground it represents. Include points A, B, K, M, N, T, X, and Y.—*Ib., March* 1895.

4. In intersection of stations what determines—
   (1) The number of stations ?
   (2) Their distance apart in plan ?
   (3) Their distance apart on the ground ?
   (4) Their relative positions ?

—*Promotion, Lieutenants, Nov.* 1891.

5. What general rules are observed in selecting the position of a base for a survey ? In intersection, why are acute and obtuse angles a source of error ? Illustrate your answer by a hand sketch.—*Ib., May* 1894.

6. Give the rules to bear in mind in selecting the position of the base of a military sketch. What approximately is a convenient distance between stations, supposing the scale of the sketch is 4 inches to 1 mile?—*Ib., Nov.* 1894.

7. What is about the maximum and minimum length which the base of a triangulation in military sketches should amount to? When, owing to the nature of the ground, it is possible to obtain only a very short base, how would you proceed? Illustrate your reply by a diagram.
—*Admission Staff College, June* 1885.

8. What general rules should, as far as possible, guide you when selecting the position of the base for a military survey, and what (approximately) are convenient distances from each other of stations of intersection when the scale is 8 inches to 1 mile? Explain the use of check-bearings.
—*Ib., June* 1890.

9. When making an intersection of stations with a prismatic compass, how do you establish the points which are nearly in prolongation of the base? What is a satellite station? When is a satellite station necessary?
—*Ib., May* 1891.

10. Illustrate the principles of intersection by laying down upon the accompanying diagram (diagram II.) a base line suitable to its area, and stations sufficient for sketching the ground delineated thereon. Conspicuous objects for this purpose may be supposed to exist at any convenient places on the diagram. The intervisibility of stations must be duly considered.—*Ib., May* 1892.

11. A deliberate sketch of a position is to be made. What general rules would guide you in selecting a base for the survey, and in your selection of stations? On what does the number of stations chiefly depend, and what is a convenient distance for the stations to be apart on the plan?
—*Ib., May* 1893.

12. Show on the map (diagram XV.) the base and points you would select if ordered to make a survey of the area shown, and describe generally how you would proceed to execute the sketch with a plane-table, without reference to contouring. Illustrate your answer by reference to the points you have marked on the map, and give the reasons which induced you to decide on the base you have chosen.

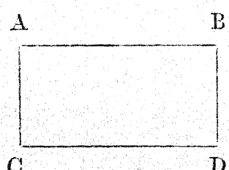
—*Militia Competitive, March* 1896.

13. Form a diagram for a base and triangulation from the points as shown in the accompanying diagram. (See diagram XVII.)—*Ib., Sept.* 1895.

GROUP XXI.

CONTOURING.

1. Construct a parallelogram measuring $3\frac{1}{2}$ inches by 2 inches, and letter it A, B, C, D, as in sketch.



Supposing these to be four points fixed by intersection, show by normal contours that D is about 75 feet higher than C, 90 feet higher than B, and 130 feet higher than A. *All the slopes to be slightly concave in section.* Scale $\frac{1}{7920}$.

—*Militia Competitive, March* 1890.

2. Being ordered to sketch a position, you have only time to draw the detail shown in diagram XII. and note down the altitudes thereon indicated. Draw the contours at 30 feet

vertical interval from the observations made, assuming the lowest level to pass through the point marked 90. Contours to be shown in red.—*Ib.*, *Sept.* 1891.

3. From a point X, where two watercourses meet, the bearings of C is 12°, of B 46°, and of A 67°. B is a hill-top, distant from X 595 yards.

From B, C bears 277° and A bears 170°. The fall from C to X is $\frac{1}{60}$, the fall from A to X is $\frac{1}{30}$. At B the angles of depression towards X are 3° for 224 yards, 12° for 60 yards, and 3° for the remainder. At B the angles of depression towards A are 5° for 76 yards, 8° for the remainder. From B the angle of depression to C is 6° throughout.

Sketch the ground on a scale of 12 inches to 1 mile, with normal contours.

N.B.—Take the height of hill-top B anything you like over 130 feet. In order to make the contours fit in properly, it will be necessary to make two alterations in the question—namely, the slope from B towards X should be 3½° (not 3°) for 224 yards. The angle of depression from B towards A should be 5° for 90 yards, not 76 yards as stated.

—*Ib.*, *Sept.* 1891.

4. A is a hill-top 70 feet above sea-level, and from A section lines are run down to high-water mark as follows:—

ABC, bearing 180°; A to B 350 yards, slope 2°; the remainder BC slopes 1°.

ADE, bearing 130°; A to D 290 yards, slope 1½°; the remainder DE slopes 4°.

AF, bearing 215°, with a uniform slope of 2½°.

Contour the above hill on the following conditions: Scale of plan 8 inches to a mile; contours at 10 feet vertical interval.

Calculate the heights of B and D above high-water mark.
—*Ib.*, *Sept.* 1892.

5. Take three points A, B, C, in the form of an equilateral triangle of 3 inches side. Point A as 21 feet, B as 19 feet, and C as 14 feet high respectively. A pond lies in the centre,

its outflow being between B and C, a col between A and B 7 feet high, and another col between A and C 11 feet high. Draw the contours 0, 5, 10, 15, and 20 feet.

—*Ib., Sept.* 1893.

6. *Note.*—In order to allow the river in this question to flow from A to B without running up-hill, the general slope of the spur from F to B should be altered from 5° to 6°. Also, as the existence of a knoll in a uniform slope is a physical impossibility, that feature should be omitted from the spur DA.

Plot the following: Scale $\frac{1}{10560}$; distance from A to B 1220 yards.

Intersections at A.

Bearing of D = 29°	Bearing of B = 93°
" E = 41°	" H = 130°
" F = 81°	

Intersections at B.

Bearing of H = 248°	Bearing of E = 321°
" A = 273°	" F = 350°
" D = 300°	

Resected, C.

Bearing of A = 262°	Bearing of D = 338°

Resected, G.

Bearing of H = 130°	Bearing of D = 57°

Make a sketch by means of contours, and mezzotint shading according to the scale of shade, fulfilling the following conditions:—

In the above plotting, a line through the points D, E, F gives the edge of a plateau, from which two spurs run in the direction DA, FB.

From A is a river ACB, flowing from A to B; its average width is 50 yards.

From E towards C is a watercourse, which meets the river at C.

The following are the observations with the clinometer:—

Starting from D down the spur DA. For 190 yards is a

slope of 2°, after which distance the slope is uniform at 3° until the river-bank is reached.

At 250 yards from D on this spur there is a knoll.

The general slope of the watercourse from E towards C is 2°.

From F towards B the general slope of the spur is 5°.

—*Ib.*, *March* 1894.

7. *Note.*—In this example there are two possible heights for T. Under the circumstances perhaps the best thing to do is to strike an average.

XY is a base line 955 yards long, Y bearing 80° from X. A tower (T) bears 22° from X and 321° from Y, and a sign-post (S) bears 144° 30′ from X and 210° 30′ from Y. Construct the triangulation, and state how far apart in yards are the sign-post and tower. Give also the bearing of the tower from the sign-post. Scale $\frac{1}{10560}$.

XY is measured along a valley. From X the angles of elevation to Y, T, and S are 2°, 5½°, and 6° respectively. From Y the angles of elevation to T and S are 4° and 3° respectively. Draw the contours forming this valley at 20 feet V.I., and give the height of T above S, also the height of Y above X.—*Ib.*, *March* 1895.

8. Explain fully how you would contour a military sketch in the field.—*Ib.*, *Sept.* 1895.

9. With the assistance of a few contours show a *plateau* connected with a *ridge* by a *col*, also *spurs* and *knolls.* Indicate watersheds by dotted lines, and as concisely as possible explain how you would commence and continue to obtain the position of contours, working down one of the spurs.—*Promotion*, *Captains*, *Nov.* 1891.

10. (*a*) The length of a base AB, taken along a valley, is 600 yards.

The bearing of B from A is 95°
" a point F from A is 40°
" " F " B " 338°

The bearing of a point W from A is 156°				
"	"	W " B " 230°		
From a point A the angle of depression to B is 2°				
"	A the angle of elevation to F is 5°			
"	A	"	W " 5°	
"	B	"	F " 7°	
"	B	"	W " 6°	

The V.I. is 20 feet. R.F. of scale $\frac{1}{5068 \cdot 8}$

From the foregoing data draw in the contours.

(*b*) Give the value of the angles at F and at W.

(*c*) Give the command of F over W and of F and W over B.—*Ib.*, *May* 1894.

11. A base line AB is taken along a straight road with a uniform ascent of 2°, A being 500 and B 600 feet above datum. From A and B, as also from intermediate points, 300, 500, and 760 yards measured from A, the slopes of the ground taken at right angles to the road on one side are found to be—

	Slope.
From point A	5°
" 300	7°
" 500	10°
" 760	6°
" B	15°

Scale 6 inches to the mile. Contour the ground for every 20 feet down to contour 300 feet above datum.

—*Admission Staff College*, *June* 1885.

12. An island contains three hills, A, B, and C. From the top of B the angle of depression to A is 2°, bearing 354°, distance 1146 yards. The angle of depression of the col which connects B and A is 4°, its distance from B being 826 yards.

Resect the position of C, the bearing of A being 66° and of B 145°. At C the angle of elevation of B is observed to be 4°.

The sea is 160 yards west of C, and 45 feet below it.
" 340 " north and 400 yards east of A.
" 300 " south and 460 yards east of B.

Contour the island at 20 feet vertical intervals. Scale 6 inches to a mile.—*Ib.*, *June* 1886.

13. Draw the ground described below on a scale of 8 inches to a mile. Normal scale of horizontal equivalents.

	Triangulation.		Triangulation.
At A, bearing of	G=212° 30′	At G, bearing of	E= 55°
"	F=240° 30′	"	C= 79° 30′
"	B=255°	"	D= 9°
"	D=279°	"	F=315°
"	H=284° 30′	"	B=320° 30′
"	E=154° 15′	"	H=355° 15′
"	C=171°		

Base AG=847 yards.

F is at the junction of two streams flowing from D and E. G and C are points on one watershed; B and H are points on another watershed. A is a hill-top.

At A the vertical angles of points are observed with the clinometer.

E=5° depression.	H=1° depression.
D=6° "	G=0° 20′ elevation.
C=1° elevation.	F=3° depression.
B=0° 20′ "	

—*Ib.*, *June* 1887.

14. A stream rises in the centre of your sketch and flows for 525 yards in the direction 250° 30′; here it joins the sea. The fall of the stream is uniformly 1 in 20. The general direction of the sea-coast is north and south.

From the source of the stream the bearings of two hills A and B are observed 354° and 207° respectively; from the mouth of the stream A bears 42° and B bears 98°.

A is 150 feet above the sea; at B the angle of depression to the mouth of the stream was observed as 5°.

Sketch the ground on a scale of 8 inches to a mile, with normal contours.—*Ib.*, *June* 1888.

15. Sketch the ground described below, scale 6 inches to a mile, with contours at 20 feet intervals. Base XZ = 855 yards.

From X the following bearings were ascertained—viz.: A $142\frac{1}{2}^\circ$, B 125°, M $74\frac{1}{2}^\circ$, P 169°, S $38\frac{1}{4}^\circ$, Y $216\frac{3}{4}^\circ$, Z 103°; and from Z the following—viz.: A and B $238\frac{1}{4}^\circ$, M $341\frac{3}{4}^\circ$, P 222°, S 326°, Y $257\frac{1}{2}^\circ$.

X and Z bear from C $322\frac{1}{2}^\circ$ and 42° respectively. The heights of P, A, and M, through which points a stream flows, are 150, 85, and 50 feet above a datum level. From S, which is 20 feet above M, the elevation of X is $6\frac{1}{2}^\circ$; from Y and C, which are 120 and 55 feet above M, tributaries flow to join the main stream at A and B. The gradient of MZ is about 1 in 19. Mark the height of X.—*Ib.*, *June* 1889.

16. From A, a hill-top near the coast, 180 feet above the level of high-water mark, section lines are run down to high-water mark as follows, viz.:—

ADE ~~ABC~~, bearing 180°; AB = 410 yards, slope 4°; BC slope 7°.

ABC ~~ADE~~, bearing 215°; AD = 230 yards, slope 6°; DE slope 9°.

AF, bearing 140°; slope 5° throughout.

Contour hill-side on a scale of 12 inches to a mile with 20-feet contours.—*Ib.*, *May* 1892.

17. From a point A, 212 feet above datum, two section lines are run down to B and C, which are points on the west bank of a stream.

From A to D,	bearing 56°,	dist. 300 yds.,	ground falls 4°
" D " E,	" 64°,	" 200 "	falls 1°
" E " F,	" 64°,	" 150 "	level.
" F " G,	" 70°,	" 200 "	rises 3°
" G " H,	" 70°,	" 150 "	level.

From H to B, bearing 50°, dist. 500 yds., ground falls 2°
" A " K, " 125°, " 600 " falls 3°
" K " C, " 120°, " 800 " falls uniformly.
The river has a uniform fall of $\frac{1}{150}$ from B to C. Scale 6 inches to 1 mile; contours normal.

18. From a hill-top A three section lines are run down to the sea—viz.: AC, AF, and AJ, the points C, F, and J being on the coast. A is 175 feet high.

Along the line AC the following observations are taken:—

AB, bearing 96°, depression 2°, length 240 yards.
BC, " 104°, uniform slope, " 860 "

Along the line AF:—

AD, bearing 160°, depression 3°, length 200 yards.
DE, " 140°, elevation 2°, " 250 "
EF, " 170°, uniform slope, " 1050 "

Along the line AJ:—

AG, bearing 235°, depression 4°, length 300 yards.
GH, " 215°, level, " 120 "
HI, " 240°, elevation $2\frac{1}{2}$°, " 200 "
IJ, " 220°, depression 6° to J.

Contour the ground. Scale 6 inches to 1 mile; V.I. normal.

Suppose the prismatic compass used to have a variation of 12° E., show the true and magnetic north points in the proper conventional manner.

19. Sketch the ground described below. R.F. $\frac{1}{7920}$; V.I. normal:—

AD bears 90°, distance 520 yards.
AE " 151°, " 620 "

B and C are points on the line AD. AB=140 yards and AC=425 yards.

Two streams from B and C unite at X and then flow through E. The levels of A, B, and X are 300, 275, and 250 feet respectively. CX=350 yards. Angle of depression from B to X is 1·3°; the fall from C to X is $\frac{1}{35}$.

From A the ground falls towards E. at 1° for 180 yards,

and 2° for the remaining distance. From E the ground rises towards D at 3° for 220 yards, then 2° for the remaining distance. Mark the levels of C, D, and E. What is the angle of elevation from C to D, and the gradient from X to E?

Is E visible from A and D?

20. Plot the following on a scale of 12 inches to 1 mile, and give the length and bearing of CF. Base AB=760 yards:—

From A, B bears 344°	From B, C bears 89°
" " C " 18°	" " D " 132°
" " D " 46°	" " E " 199°
" " E " 277°	" " H " 263°
" " H " 323°	

From a point F, H bears 6° and A bears 97°. Contour the above, with normal V.I., from the following data. A=200 feet:—

From A the angles of depression to B and D are 3°
" angle " E is 4°
" " " H " $\frac{1}{2}$°
" " elevation to F " $1\frac{1}{2}$°

On the line BC the ground rises at a gradient of $\frac{1}{11}$ for 200 yards to a point M, and then falls at a gradient of $\frac{1}{14}$ to C. FH and AM are watersheds; EB and DC are watercourses. Would all the above intersections have been possible? if not, why?

21. From a hill-top A, 353 feet above sea-level, I take a bearing of 180° along a certain line to B. The angle of depression to B is 3°, and the distance AB is 338 yards.

From B, and in prolongation of the line AB, I can just see over the top of a knoll E and the top of a tower F, a point G in the watercourse of the valley below. The angle of depression to G from B is 4°. The ground from B falls to C at 7° slope, distance 462 yards.

I now let my clinometer fall, and it is so damaged as to be useless; but I continue my pacing along the section line, and

I find CD, which is level, measures 107 yards. The ascent up to the top of the knoll E is also 107 yards.

From E the ground slopes evenly down to the foot of the tower F, distance 270 yards. I ascend and measure the height of the tower; it is 33 feet.

From the foot of the tower to G is an even slope for 216 yards.

Contour the section line traversed, supposing it to be a straight spur from the hill A, and mark the heights of all the points mentioned. Scale 6 inches to 1 mile; V.I. normal.

The height of the observer's eye above the ground need not be taken into consideration.

22. Being told to survey an island, I start from a point A and make the following observations :—

From A, B bears 253°, slope uniform down at 1°
" " D " 193°, angle of depression $1\frac{1}{2}$° to D.
" " C " 283°, " " to col. between A and C is $2\frac{1}{2}$°
" " E " 223°
" " F lies east, angle of depression 6°

D is the top of a perpendicular cliff overhanging the sea.

I then pace to B, 1146 yards, and there make the following observations :—

From B, C bears 13°, angle of elevation $2\frac{1}{2}$°
" " E and D bear 133°, and the angle of depression to E is 3°

The col between A and C is on the same level as B.

H lies west of B, angle of depression 5°; G lies north of C, angle of depression 8°. A is 165 feet above sea-level. F, G, and H, are points on the sea-coast. Between B and C lies a valley. From near A a stream runs down to E and then turns south to the sea.

Contour the above with normal V.I. Scale 4 inches to 1 mile.

23. A hill-top A is 140 feet above the sea-level, and from it section lines are run down to high-water mark as follows :—

ABC, bearing 180°; A to B 444 yards, slope 3°; the remainder BC slopes 2°.

ADE, bearing 210°; A to D 302 yards, slope 6°; the remainder DE slopes $2\frac{1}{2}$°.

AF, bearing 140°, with a uniform slope of 4°.

Contour the above hillside with a V.I. of 20 feet, and mark the heights of B and D above high-water. R.F. $\frac{1}{7920}$.

GROUP XXII.

MAP-READING.

1. In the accompanying diagram (see diagram XI.) which of the points marked A, B, C, D, &c., are of the greatest elevation above the lowest contour? Which of the points comes next in elevation, and which takes the third place? The contours having a V.I. of 25 feet, give the respective elevations in feet above the datum level of the points you have enumerated.—*Militia Competitive, March* 1891.

2. Assuming the scale of the accompanying map (diagram XIV.) to be 8 inches to 1 mile, and the vertical interval of the contours to be 15 feet. Figure all the contours in feet round the margin of the map, taking the lowest contour as zero. Also figure the elevation in feet of the highest point on the map.—*Ib., March* 1893.

3. How do you decide from an inspection of the detail on the diagram (diagram I.) which is the lowest contour on it? and assuming this to be zero, write down the height of A, assuming that the scale of the diagram is $\frac{1}{15840}$ and the V.I. is 15 feet.—*Ib., Sept.* 1893.

4. Number on the map (diagram V.) the contours from the lowest to the highest.—*Ib., March* 1895.

5. Express fractionally the gradients on the road *a b* (see diagram II.) What is the angle of elevation from *a* to D?
—*Admission Staff College, May* 1892.

6. Diagram XV. is contoured in such a way that the horizontal equivalent for a slope of $2\frac{1}{2}°$ is 191 yards. The lowest contour shown is at a height of 200 feet above the datum level. Figure every contour on the map, writing the figures in red ink (if you have any) *on* the contour to which they refer.—*Militia Competitive, March* 1896.

GROUP XXIII.

EYE-SKETCHING.

1. As a regular base and triangulation are not used in sketching without instruments (eye-sketching), state how the position of surrounding points of importance are fixed upon the sketch.—*Militia Competitive, March* 1886.

2. In traversing a road in eye-sketching, having paced up to B from A, how do you ascertain the direction of C, the next forward object to which you are about to pace?
—*Ib., March* 1886.

3. Explain "traversing without instruments," giving in illustration a hand-sketch showing three stations. What are the advantages and disadvantages of this system as compared with "traversing with the prismatic compass"?
—*Ib., March* 1892.

4. Explain how to execute an "eye-sketch." A sketching-board, long ruler, paper, and pencil are at your service, but no instruments.—*Ib., March* 1884.

5. In making an eye-sketch without the aid of instruments,

show how you would get the north point with the aid of a watch and the sun. Explain fully the reasons for this method of procedure.—*Promotion, Captains, May* 1892.

6. When sketching without instruments, what method would you adopt to obtain and show the true north approximately?—*Ib., November* 1892.

7. Having other requisites, but no instruments, how will you execute a military sketch?

—*Promotion, Lieutenants, May* 1895.

8. Describe fully how you would set about making an "intersected" sketch of a portion of ground without other instruments than a drawing-board and a ruler.

—*Ib., Nov.* 1895.

GROUP XXIV.

FINDING POSITION BY RESECTION OR OTHERWISE.

1. Three fixed points on your plane-table are visible from your position X. Show by sketches how to find your position—

(*a*) With the magnetic needle.

(*b*) With the plane-table sight-vane only and without the magnetic needle.—*Militia Competitive, March* 1890.

2. The positions of the points A, B, C, and D having been already fixed, explain how you would resect your position at ⊙ II. with a plane-table without the aid of the magnetic needle (see diagram XIII.)—*Ib., Sept.* 1891.

3. Imagine yourself to be standing at some point in the piece of country represented by the accompanying map (diagram XIV.)

You have a prismatic compass, and with it you observe the bearings of a steeple at R to be 293° and of a tower at Q to be 239°. Mark your position on the map, assuming that the vertical marginal lines of the map run magnetic north and south.—*Ib., March* 1893.

4. Show on the diagram (diagram IV.) how you would fix the position of the bridge by resection.—*Ib., Sept.* 1894.

5. Explain the most convenient method of resection with the plane-table, three fixed points being available but no compass. What guides the sketcher in his choice of stations with this object?—*Promotion, Lieutenants, Nov.* 1891.

6. In working with a plane-table show how you would resect your position, three fixed points being available but no compass.—*Promotion, Captains, May* 1892.

7. In working with a prismatic compass explain how you would resect your position, three known points on your sketch being visible from the place where you are standing. Plot on a scale of 6 inches to a mile the position of the point D from the following data:—

The bearing of B from A is 72°, and the distance 550 yards. C bears 130° from B, and is 660 yards distant. At D, A bears 310°, B is due magnetic north, and C bears 69°. What is the distance from C to A?—*Ib., Nov.* 1892.

Note—The words "B is due magnetic north" are totally unnecessary, besides being slightly wrong. They should be disregarded when solving the problem, or if they are allowed to stand, the distance BC should be taken as 650 yards instead of 660.

8. Explain fully how you would find your place approximately on an Ordnance map on the ground with a compass, supposing you were able to recognise in the country two distant points shown on the map.—*Ib., Nov.* 1893.

9. How would you identify upon an Ordnance Survey

map the point corresponding to the place at which you are standing, supposing there were no houses, roads, or other easily identified objects near the spot—

(*a*) If provided with a prismatic compass?

(*b*) If unprovided with any instruments?

—*Admission Staff College, June* 1885.

10. Explain how you would determine on a map, if unprovided with instruments, the spot corresponding to your position, supposing you can recognise two or three distant mountain-peaks which are shown on the map.

—*Ib., June* 1887.

11. A is a point which has been determined on your sketch —scale 6 inches to 1 mile—by intersections with prismatic compass. You wish to commence a traverse near A, but find yourself separated from it by a river which prevents you from approaching it within 400 yards. No other fixed point is visible. Draw a diagram showing how you would proceed to find your position with respect to A.—*Ib., June* 1888.

12 Under what circumstances does "resection" with the plane-table by means of what is known as the three-point problem fail to give the correct position of the sketcher? Give reasons for this failure.—*Ib., May* 1894.

13. What do you understand by the term "resection"?

What is the essential difference between resection by the plane-table and by the prismatic compass? Explain in a few words why this is so.—*Militia Competitive, March* 1896.

14. A staff officer with headquarters sends the following message to the O. C. advanced guard.

"Reference to your map. I am informed that the map is not up to date, and that there now exists a farmhouse commanding the road, also that there are cross-roads in the vicinity of X. The church at A, the tower at B, and the

cairn at C seem to be visible from these two points. Please detail two officers to supply me with sufficient information to enable me to locate the exact position of these two points on my copy of the map."

The O. C. advanced guard details Lieut. D. and Lieut. E. to supply the required information. Lieut. D. being required to fix the position of the farmhouse, sends in a piece of transparent paper of which Plate XVI. is a copy. Lieut. E. being required to fix the position of the cross-roads in the vicinity of X, sends in the following :—

"From cross-roads, church at A bears 142°, tower at B bears 207°, cairn at C bears 125°."

Criticise the utility of the information given.

15. You are given a piece of transparent paper on which are three lines meeting at a point, and you are told to fix that point on your map. Plate XVI. is the transparent paper and Plate XIV. is your map. The three points on the map through which the lines are to pass are A, B, and C. Fix the point.

Note – Owing to a slight diminution of the angles in the process of printing the points X Y V W are not quite correctly placed, but the principle is not affected.

GROUP XXV.

SETTING MAPS.

1. Having with you a common compass and an Ordnance map of the country, how would you place your plan so that its position should correspond to that of the country? Under what circumstances would such a proceeding be utterly abortive?—*Militia Competitive, March* 1886.

2. I wish to set up my plane-table at *a* (diagram I.) The points C, D, and E are already fixed on it. Explain how I could do this without the aid of the magnetic needle.

—*Ib., Sept.* 1893.

3. You possess the map of a district which you do not know. How will you set up the map so as to recognise the various places around?—*Promotion, Lieutenants, May* 1894.

4. A map of a strange country is given to you as a guide for the same. How will you set the map so as to make use of it?—*Ib., Nov.* 1894.

5. In comparing a map with a piece of country from some commanding station identified on the former, explain clearly how you would set your sketch to correspond in position to that of the country, supposing you had no instruments with you?—*Admission Staff College, June* 1888.

6. In a part of the country which you do not know you are given an Ordnance 1-inch map, and are told to set it correctly and to fix your position on it. Explain how you would do this.—*Ib., May* 1894.

7. What do you understand by the expression "setting a map"?

Describe how you would proceed to "set" a map—

(*a*) When you can identify on it the exact spot on the ground on which you are standing.

(*b*) When you are uncertain of your position, and want to use the map without leaving the spot where you are standing.—*Promotion, Lieutenants, Nov.* 1895.

GROUP XXVI.

VISIBILITY.

1. Which of the points A, B, C, E, &c., as lettered on the diagram (see diagram XI.), are visible from the point D?
—*Militia Competitive, March* 1891.

2. Assuming the scale of the accompanying map (diagram XIV.) to be 8 inches to 1 mile, and the vertical intervals between the contours to be 15 feet, what would be the height above the lowest contour of a spire at R which could just be seen by an observer at F, supposing the height of his eye to be 5 feet?—*Ib., March* 1893.

3. Without the aid of a section show which of the points F, D, and C are visible or not visible from the point *b* (see diagram I.) Give clear reasons for your replies.
—*Ib., September* 1893.

4. Is D visible from C (see diagram VIII.)? This point is to be decided without the aid of a section, and the reason for arriving at your conclusion is to be clearly given.
—*Promotion, Captains, Nov.* 1893.

5. Show how far a man standing at C can see the ground in the direction of B (see diagram VI.)

Show that though it is theoretically possible for a sentry at C to see the whole of the ground along the line CD up to the eastern extremity of the sketch, practically it is possible that a cavalry vedette at D might be unseen by the sentry. What is the reason of this?
—*Promotion, Lieutenants, May* 1892.

6. Show by a coloured line on the diagram the route by which a picquet might be marched from A into the neigh-

bourhood of B, without being seen by the sentries of the latter (see diagram II.)—*Admission Staff College, May* 1892.

7. On diagram X. mark out the ground which is unseen by a sentry on the church tower at X, his eye being 340 feet above datum.—*Ib., May* 1894.

8. A balloon section let up a captive balloon at the point marked T (see diagram XV.), with the object of seeing the ground at X. At what vertical height above the ground at T will X become just visible to the observer in the car of the balloon ?—*Militia Competitive, March* 1896. The vertical interval between the contours is 25 feet

9. A sentry is posted at the cross-roads at the point marked Y on the accompanying map (see diagram XVIII.) Show by a dark wash or pencil shading all the ground on the map to the westward of the line drawn through that point which cannot be seen by him, assuming his eye to be at the level of 675 feet.—*Ib., Sept.* 1896.

10. On Plate XIV. determine where the sea becomes visible to an observer at D looking along the line DCFK. The height of the observer's eye is 5 feet above the ground.

11. On Plate XIV. determine how much of the ground between E and L would be invisible to an observer at D. The height of the observer's eye is not to be considered.

GROUP XXVII.

GRADIENTS ADMITTING OF MANŒUVRES.

1. If a gradient of between 10° and 12° occurred on your road, would you make any remark as to its ascent by guns or by heavy waggons?—*Militia Competitive, Sept.* 1886.

2. What is the steepest slope up which field artillery could be taken for manœuvre?—*Ib., March* 1893.

3. What slopes are practicable for the manœuvres or movements of troops?—*Promotion, Lieutenants, May* 1894.

GROUP XXVIII.

RECONNAISSANCE OF ROADS, RIVERS, ETC.

1. What are the chief points as regards the actual road itself which should be particularly reported upon in a road reconnaissance?—*Militia Competitive, March* 1884.

2. In making a road reconnaissance, mention the headings under which you would report on any bridge.

—*Ib., Sept.* 1886.

3. Enumerate the different headings under which information should be given as to roads in a road reconnaissance.

—*Ib., March* 1887.

4. Enumerate the points which should be reported on under the heading "Rivers" in a road report.

—*Ib., March* 1890.

5. Give a summary of the details on which you would have to report under the heading of "Bridges" in making a road report.—*Ib.*, *March* 1891.

6. On what scales are road sketches usually made?

In a road report what information would be given under the headings—(*a*) The Roadway; (*b*) the Rate of Marching; (*c*) Positions?—*Ib.*, *Sept* 1891.

7. Road reconnaissance—

(*a*) Give a summary of the details you would describe in your report under the heading "The Road."

(*b*) What are the minimum breadths of roads available for infantry in fours and guns in column?

(*c*) What are the steepest gradients of roads accessible for heavy waggons and for field guns respectively?

—*Ib.*, *March* 1892.

8. In making out a reconnaissance report, what notes would you make respecting buildings, bridges, fords, soil, rivers, woods, and defiles?—*Ib.*, *Sept.* 1895.

9. In reporting upon a road in a road reconnaissance, state what particular information is required as regards bridges, rivers, and railways.—*Ib.*, *Sept.* 1892.

10. In road reconnaissance state the information required respecting—(1) The roadway; (2) the country; (3) halting-places; (4) camping-grounds (giving dimensions for the three arms); (5) lateral communications.

—*Promotion, Lieutenants, Nov.* 1891.

11. In making a rapid reconnaissance of a river, state briefly to what points you would direct your attention.

—*Ib.*, *May* 1892.

12. In making a reconnaissance of a road, what are the chief points you would report upon with regard to the bridges which the road passed over?—*Promotion, Captains, Nov.* 1892.

13. You are to report upon a position for the defence of which the troops with which you are doing duty are *en route*. Give the headings only of the report you would make.
—*Promotion, Lieutenants, May* 1893.

14. What are the main points to be attended to in the reconnaissance of a railway?
—*Promotion, Captains, Nov.* 1893.

15. What are the salient points to bear in mind when furnishing the report of a position?
—*Promotion, Lieutenants, May* 1894.

16. In drawing up a road report, what information would be given under the heading "Bridges"?—*Ib., Nov.* 1894.

17. In making a road reconnaissance, what special points would you note in your report of the following details, namely:—

(*a*) Bridges over which the road passes?
(*b*) Towns and villages through which it runs?
—*Promotion, Captains, Nov.* 1894.

18. Enumerate the different headings under which most of the information connected with the defence of a position can be reported on.—*Promotion, Lieutenants, May* 1895.

19. When using the authorised road report form, what information is given under the head "The Road"?
—*Ib., May* 1895.

20. Enumerate the headings under which the reconnaissance of a river should be reported on when it is used as a defensive obstacle?—*Admission Staff College, June* 1889.

21. In drawing up a road report, what information would you give under the heading "The Country"?
—*Ib., June* 1890.

22. (*a*) In a road report what information would be given under the heading "Rivers"?

(*b*) On what does the fordability of rivers depend?

Should the conditions be favourable, give the depths at which fords are practicable for the three arms.

—*Ib.*, *August* 1895.

GROUP XXIX.

CONTENTS OF STACKS OF HAY AND STRAW, ETC.

1. (*a*) Give approximately in tons the contents of a stack of hay which is 6 yards long, 4 yards broad, 8 feet to the eaves, and 13 feet to the ridge from the bottom of the stack.

(*b*) What would be the contents of a stack of straw having the same dimensions as the stack of hay?

—*Promotion, Lieutenants, May* 1893.

2. Give approximately in tons the amount of hay and straw contained in two stacks (one of hay and the other of straw), each of which measures 8 yards long, 4 yards broad, height 9 feet to eaves and 15 feet to ridge exclusive of thatch.

3. Give approximately in tons the contents of two circular stacks (one of hay and one of straw) which measure 66 feet in circumference, height 12 feet to eaves and 21 feet to apex exclusive of thatch.

4. Give approximately the amount in lb. of oats contained in a box 6 feet long, $4\frac{1}{2}$ feet wide, and 4 feet deep.

GROUP XXX.

SUPPLY OF WATER IN RUNNING STREAMS.

1. Give the breadth, depth, and rate of flow of a stream that would supply water sufficient for 15,000 men for twenty-four hours. Show how you arrive at your answer.
—*Promotion, Captains, Nov.* 1891.

2. A rivulet 2 feet broad and 3 inches deep runs at the rate of 40 feet a minute. How many men will it supply daily?—*Admission Staff College, June* 1890.

3. Describe the method of finding the rapidity of a stream. Give the breadth, depth, and rapidity of a stream that would supply water sufficient for 18,000 men for twenty-four hours.
—*Ib., May* 1892.

4. What should be the rate of flow of a stream 2 feet broad and 6 inches deep to supply water for 18,000 men for twenty-four hours?

5. If 8 gallons per diem be considered a sufficient supply of water per man, how many men could be supplied from a stream averaging 4 feet broad, 3 inches deep, and flowing at the rate of 25 feet a minute?

6. A circular well is 8 feet in diameter; the normal depth of water is 12 feet. The well is pumped out until only 5 feet of water remains, and then it is left to fill again, which it does in 1 hour. How many men would that well supply daily, allowing 6 gallons a-day for each man?

GROUP XXXI.

CALCULATION OF HORIZONTAL ANGLES FROM GIVEN BEARINGS.

1. From a point A the bearing of B is 20° and of C 85°; what is the value of the angle subtended by BC?

The direction of AC (as above) having been laid down, you are required with your prismatic compass to lay off a right angle from the point C. Explain how you would do so.

—*Promotion, Captains, Nov.* 1891.

2. In the triangle ABC, B bears 300° from A and 30° from C, from which to A the bearing is 55°. Calculate the values of the angles at A, B, and C.

—*Militia Competitive, March* 1883.

3. In the figure ABCD, AB bears 34°, BC bears 324°, CD bears 214°, and DA bears 144°. Calculate the interior angles of the figure.

4. Three officers, A., B., and C., are standing at three points in the country,—

A.	takes a bearing	on	B.	reading	33°
B.	"	"	C.	"	264°
C.	"	"	A.	"	149°

A.'s compass has a variation of 11° W.
B.'s " " 17° "
C.'s " " 8° E.

If A. and C. are 800 yards apart, how far is B. from C. and B. from A., and what are the interior angles at A., B., and C.?

5. Two officers start from W to reach Z by different roads.
A. reads 25° bearing to X, and from X he reads 280° to Z.
B. reads 310° to Y, and from Y 8° to Z.
A.'s compass has a variation of 10° E. and B.'s 12° W.
What are the angles at W, X, Y, and Z?

GROUP XXXII.

EXERCISES IN THE USE OF THE MARQUOIS SCALES.

1. If you were required to draw by means of your marquois rulers and triangle parallel lines at the following distances apart, say which scale you would use in each case:—(*a*) 1 inch, (*b*) $\frac{1}{2}$ inch, (*c*) $\frac{1}{4}$ inch, (*d*) $\frac{1}{6}$ inch, (*e*) $\frac{1}{8}$ inch, (*f*) $\frac{1}{9}$ inch, (*g*) $\frac{1}{12}$ inch, (*h*) $\frac{1}{16}$ inch, (*i*) $\frac{1}{40}$ inch, (*j*) $\frac{2}{3}$ inch, and (*k*) $\frac{5}{7}$ inch. Also (*l*) ·12 inch, (*m*) ·2 inch, (*n*) ·15 inch, (*o*) ·7 inch, (*p*) 1·4 inch, (*q*) ·04 inch, (*r*) 1·25 inch.

2. It is required to draw parallel lines representing distances a certain number of *feet* apart; which marquois scale would you use when drawing to the following scales?—(*a*) 10 feet to 1 inch, (*b*) 12 feet to 1 inch, (*c*) $8\frac{1}{3}$ feet to 1 inch, (*d*) $6\frac{2}{3}$ feet to 1 inch, (*e*) $3\frac{4}{7}$ feet to 1 inch, (*f*) 8·75 feet to 1 inch, (*g*) $2\frac{1}{2}$ yards to 1 inch, (*h*) $3\frac{1}{8}$ yards to 1 inch, (*i*) R.F. $\frac{1}{25}$, (*j*) R.F. $\frac{1}{100}$, (*k*) R.F. $\frac{1}{72}$, (*l*) R.F. $\frac{1}{75}$, (*m*) R.F. $\frac{1}{108}$, (*n*) R.F. $\frac{1}{80}$, (*o*) R.F. $\frac{1}{105}$, (*p*) R.F. $\frac{1}{90}$, (*q*) R.F. $\frac{1}{2000}$.

3. It is required to draw parallel lines representing distances a certain number of *yards* apart; which marquois scale would you use when working to the following scales?—(*a*) R.F. $\frac{1}{288}$, (*b*) R.F. $\frac{1}{720}$, (*c*) R.F. $\frac{1}{2160}$, (*d*) R.F. $\frac{1}{2700}$, (*e*) R.F. $\frac{1}{2880}$, (*f*) R.F. $\frac{1}{6300}$, (*g*) R.F. $\frac{1}{1620}$, (*h*) R.F. $\frac{1}{21600}$, (*i*) R.F. $\frac{1}{8400}$, (*j*) R.F. $\frac{1}{9000}$, (*k*) R.F. $\frac{1}{10000}$, (*l*) R.F. $\frac{1}{12000}$. Also (*m*) 30 yards to 1 inch, (*n*) 80 yards to 1 inch, (*o*) $6\frac{1}{4}$ yards to 1 inch, (*p*) 150 yards to 1 inch, (*q*) 175 yards to 1 inch, (*r*) 8·8 inches to 1 mile, (*s*) 6·6 inches to 1 mile, (*t*) 10·56 inches to 1 mile, (*u*) $2\frac{1}{5}$ inches to 1 mile.

GROUP XXXIII.

ACCOMMODATION FOR MEN AND HORSES.

1. In passing along a street 285 yards in length, you observe that the houses on each side are on an average two storeys high and two rooms deep. Roughly estimated, how many men could be accommodated in these houses for one night?

2. How many men could be accommodated in a hall 25 feet wide and 42 feet in length?

3. How many horses could be stabled in a barn 25 feet wide and 40 feet in length?

GROUP XXXIV.

MISCELLANEOUS EXAMPLES.

1. How many methods are there of obtaining the position of objects with the prismatic compass? Describe each method fully.—*Militia Competitive, March* 1886.

2. What do you understand by "reference points" in contouring, and how would you make use of them?
—*Ib., March* 1891.

3. Before making use of a map in the field it is necessary to ascertain if such map is fairly correct and up to date. Give two or more methods for arriving at this result.
—*Promotion, Captains, Nov.* 1891.

4. In making a reconnaissance of a river, show how you would obtain its width by means of the prismatic compass. —*Ib., Nov.* 1892.

5. Give briefly the details of making a deliberate military sketch of a position, and give the main points to attend to in the various steps.—*Promotion, Lieutenants, Nov.* 1893.

6. Describe briefly the usual simple methods of determining the direction of true north.

—*Promotion, Captains, May* 1894.

7. What are the various terms applied to the different velocities of rivers? After each state the velocity in miles per hour.—*Ib., May* 1894.

8. Explain how you would obtain the data for furnishing a sketch with a north point if you were serving at the place represented. Illustrate your explanation by laying down a north point in accordance with your assumed data on diagram VIII.—*Admission Staff College, June* 1887.

9. If a sketch such as diagram II., but without the information given at foot, fell into your possession on service, how would you ascertain (*a*) its scale, (*b*) the vertical interval between the contours, (*c*) the magnetic and true north?

—*Ib., June* 1887.

10. Supposing that a plan were given you furnished with no north point, or information as to the vertical interval of the contours, how would you ascertain them on the ground represented, if you were provided with any of the sketching instruments you are accustomed to use.—*Ib., June* 1889.

11. In sketching hilly country do you recommend working up hill or down? Give your reasons.—*Ib., May* 1891.

12. You are in charge of a contact squadron on service in

a civilised country and lose your map. On arriving at the nearest town you secure the best map procurable. How will you test its being fairly accurate?—*Ib., May* 1893.

13. Describe fully how you would contour a military sketch.—*Ib., May* 1894.

14. In military sketches hills are represented by contours. (1) What purposes do these contours serve? (2) What is understood by the "normal system" of contours, and how is this system secured?—*Promotion, Captains, Nov.* 1895.

15. You are given a large scale map for use on manœuvres, and on visiting the ground to post a picquet, you find that the part of the map with the scale on it has been inadvertently cut off. Describe what you would do in order to ascertain the scale of the map.—*Promotion, Lieutenants, Nov.* 1895.

16. You are given a 6-inch Ordnance map on which are shown contours at 100 feet V.I., and are required to contour the same at 10 feet V.I.—that is, to interpolate nine contour lines between the 100-feet contours already shown. Explain how you would set about this operation on arriving on the ground the map represents.

17. State the bearings in degrees corresponding to the following points of the compass—viz.: N.W. by W., W.S.W., E. by N., S.W. by S., S.E. by S., E.S.E.

—*Militia Competitive, March* 1896.

18. An officer standing on a cliff 445·1 feet above sea-level sees a ship sailing straight towards him. He finds the angle of depression to the hull of the ship to be $\frac{1}{2}°$, and exactly ten minutes later $\frac{3}{4}°$. At how many knots per hour is the ship steaming? 1 knot = 2000 yards.—*Ib., March* 1897.

19. A map of which the R.F. equals $\frac{1}{6336}$ is contoured on the "normal scale." If a river falling uniformly 20 inches

per mile ran straight across the map, what length on the scale of the map would represent the horizontal distance between the contours which cross the river?

—*Ib.*, *March* 1897.

20. The magnetic bearing of a distant point P is found to be 210°. The angle between this point and the sun when on the meridian is 5°. What is the variation of the compass used—(*a*) when P is west of the meridian? (*b*) when it is east of the meridian?—*Ib.*, *March* 1897.

ANSWERS.

GROUP I.

SCALES, PLAIN AND COMPARATIVE.

CLASS I.—Expressions.

1. $\frac{1}{12672}$, $\frac{1}{39600}$.

2. A representative fraction is the ratio, expressed as a fraction, which the lengths on a plan bear to their corresponding distances on the ground. It is necessary that it should be stated on the plan for purposes of easy comparison with other maps, and also that a scale of any required units of measurement may be made for it.

$\frac{1}{248795{\cdot}81}$, $\frac{1}{635{\cdot}29}$.

3. $\frac{1}{3168}$, $\frac{1}{158400}$, $\frac{1}{480}$.
$555{\cdot}\dot{5}$ yards to 1 inch.
$833{\cdot}\dot{3}$ yards to 1 inch.
12·672 inches to 1 mile.
1·408 inches to 1 mile.

4. $\frac{1}{253440}$, $\frac{1}{3168}$.
$694{\cdot}\dot{4}$ yards to 1 inch.
1944·4 yards to 1 inch.
5·28 inches to 1 mile.
2·112 inches to 1 mile.

5. $\frac{1}{52800}$, $\frac{1}{190080}$.
$8066{\cdot}\dot{6}$ yards or $4{\cdot}58\dot{3}$ miles.
29,040 yards or $16\frac{1}{2}$ miles.

CLASS II.—Construction of Scales, R.F. given.

1. 5·276 inches will represent 2600 man's paces.
5·681 inches will represent 2400 horse's paces.
See Plate I. fig. 1.

2. See answer to No. 2, Class I.
5·681 inches will represent 400 yards.
6·212 inches will represent 400 mètres.

3. 7·20 inches will represent 900 paces.

4. 7·673 inches will represent 80 toises.
6·666 inches will represent 300 archines.

5. 5·4 inches will represent 3000 yards.

6. 5·76 inches will represent 1600 yards.
Distance from A to B is 2560 yards.

7. 6 inches will represent 1000 strides.
5·333 inches will represent 2000 steps.
5·6 inches will represent 700 rises.

8. 5·714 inches will represent 1200 horse's paces.
5·833 inches will represent 1400 man's paces.

9. 5·871 inches will represent 700 revolutions.
6·082 inches will represent 2000 paces.

10. Of feet.

11. Of furlongs.

12. Of mètres, each 39·37 inches long.

CLASS III.—Construction of Scales, R.F. not given.

1. 6·628 inches will represent 20 versts. R.F. $\frac{1}{126720}$.

2. 5·897 inches will represent 14 miles.

R.F. $\frac{1}{150398{\cdot}55}$, which may be taken as $\frac{1}{150400}$. The distance between the villages is 8·19 miles.

3. 5·877 inches will show 1400 yards. R.F. $\frac{1}{8574{\cdot}\dot{5}\dot{4}}$.

4. 6·116 inches will represent 30 feet. R.F. $\frac{1}{58{\cdot}86}$.

5. 5·435 inches will represent 8 miles. R.F. $\frac{1}{93253}$.

6. 5·805 inches will represent 1600 yards. R.F. $\frac{1}{9921{\cdot}24}$.

7. 5·795 inches will represent 1700 yards. R.F. $\frac{1}{10560}$.

8. R.F. $\frac{1}{15000}$.
5·249 inches will represent 2000 mètres.
5·28 inches will represent 100 chains.

9. 10·98 inches to 1 mile. R.F. $\frac{1}{5770{\cdot}49}$.

This is probably meant for 11 inches to a mile, and if the examiner had put 3·$\dot{6}$ inches in place of 3·66 inches, the scale would have been exactly 11 inches to 1 mile.

10. 5·714 inches will represent 2000 yards.
5·028 inches to 1 mile. R.F. $\frac{1}{12600}$.

11. 5·528 inches will represent 3000 steps walking.
5·535 inches will represent 2000 steps trotting. R.F. $\frac{1}{21120}$.

12. 5·996 inches will represent 12 miles.

R.F. $\frac{1}{126792 \cdot 45}$, which may be taken as $\frac{1}{126800}$.

13. 5·113 inches will represent 2000 yards. R.F. $\frac{1}{14080}$.

14. 5·965 inches will represent 1600 mètres. R.F. $\frac{1}{10560}$.

15. 5·76 inches will represent 1600 yards.

R.F. $\frac{1}{10001 \cdot 25}$, which may be taken as $\frac{1}{10000}$.

16. 5·85 inches will represent 13,000 mètres.
5·762 inches will represent 14,000 yards.

R.F. $\frac{1}{87466 \cdot \dot{6}}$, which may be taken as $\frac{1}{87460}$.

17. 5·524 inches will represent 25 versts. R.F. $\frac{1}{190080}$.

18. R.F. $\frac{1}{61952}$.

19. 6 inches will represent 3000 yards. R.F. $\frac{1}{18000}$.

20. R.F. $\frac{1}{10000}$. 5·40 inches will represent 1500 yards.

GROUP II.

DIAGONAL SCALES.

1. 6·$\dot{6}$ inches will represent 60 miles. R.F. $\frac{1}{570240}$. (See Plate I. fig. 2.)

2. 5·464 inches will represent 800 yards. R.F. $\frac{1}{5270 \cdot 5}$.

3. 5·454 inches will represent 600 yards. R.F. $\frac{1}{3960}$.

4. 5·681 inches will represent 10,000 feet. R.F. $\frac{1}{21120}$.

5. 6 inches will represent 60 yards.

6. 6·753 inches will represent 400 feet. R.F. $\frac{1}{710 \cdot 77}$.
Thicken a line corresponding to 217 feet.

7. 5·28 inches will show 5 miles.

8. 5·905 inches will represent 180 mètres.

9. 5·769 inches will represent 10 miles. R.F. $\frac{1}{109824}$.

GROUP III.

VERNIER SCALES.

1. See Plate I. fig. 3.

2. See Plate I. fig. 4.

3. See Plate I. fig. 5.

4. 5·25 inches will represent 2500 revolutions.

5. See Plate I. fig 6.

6. See Plate I. fig. 7.

7. To $\frac{1}{100}$ of an inch.

GROUP IV.

SCALES DEDUCED FROM AREAS.

1. 5·6 inches will represent 1800 yards.

R.F. $\frac{1}{11567 \cdot 9}$, which may be taken as $\frac{1}{11568}$.

2. 5·677 inches will represent 2500 yards. R.F. $\frac{1}{15840}$.

3. The scale is 4 inches to 1 mile. R.F. $\frac{1}{15840}$.
5·969 inches will represent 2400 mètres.

4. 5·567 inches will show 400 yards. R.F. $\frac{1}{2586 \cdot 66}$.

Make a diagonal scale, and mark with a cross at each end a length of 275 yards.

5. 5·704 inches will represent 900 feet. R.F. $\frac{1}{1893 \cdot 24}$.

6. 5·567 inches will represent 100 yards. R.F. $\frac{1}{646 \cdot 665}$.

7. 3 inches to 1 mile. R.F. $\frac{1}{21120}$.

8. R.F. $\frac{1}{14167 \cdot 6}$.

9. 5·16 inches will represent 1000 yards. R.F. $\frac{1}{6969 \cdot 6}$.

10. 5·08 inches will represent 4000 yards. R.F. $\frac{1}{28338}$.

11. 5·668 inches will represent 60 yards. R.F. $\frac{1}{381 \cdot 051}$.

GROUP V.

TIME SCALES.

1. 5·5 inches will represent 20 hours. R.F. $\frac{1}{633600}$. See Plate I. fig. 8.

2. 6 inches will represent 20 hours. R.F. $\frac{1}{633600}$.

3. 6·476 inches will represent 4 hours.

4. 5·4 inches will represent 10 minutes.

5. 5·22 inches will represent 10 minutes.

6. 5·808 inches will represent 1 hour cantering.
4·224 inches will represent 1 hour trotting.

7. 6·336 inches will represent 1 hour's march for infantry.
5·28 inches will represent $\frac{1}{2}$ hour's march for cavalry.

8. R.F. $\frac{1}{15840}$.

9. 5·068 inches will represent 40 minutes.

GROUP VI.

CORRECTION OF SCALES MADE FROM WRONG PREMISES.

1. 5·727 inches will represent 1200 yards. R.F. $\frac{1}{7542 \cdot 857}$.

2. 5·819 inches will represent 1800 yards. R.F. $\frac{1}{11133 \cdot 63}$.

3. 5·41 inches will represent 2500 yards. R.F. $\frac{1}{16632}$.

4. $\frac{1}{10032}$.

5. 5·974 inches will represent 1800 yards. R.F. $\frac{1}{10845 \cdot 405}$.

6. 5·47 inches will represent 1000 yards. R.F. $\frac{1}{6577 \cdot \dot{7}}$.
The pacing was $6\frac{56}{99}$ per cent too short.

7. 5·844 inches will represent 1800 yards. R.F. $\frac{1}{11088}$.

8. 5·69 inches will represent 1500 paces. R.F. $\frac{1}{8712}$.

9. R.F. $\frac{1}{9600}$.

10. R.F. $\frac{1}{8640}$.

11. 34 inches.

12. 5·775 inches will represent 1200 yards. R.F. $\frac{1}{7480}$.

GROUP VII.

SCALES OF HORIZONTAL EQUIVALENTS.

1. H.E. for 1° is represented by 1·488 inches.
   H.E. " 2° " ·744 " &c., &c.
See Plate I. fig. 9.

2. H.E. for 1° is represented by 1·30 inches, &c., &c.

3. The term "horizontal equivalent" means the distance in which a given difference of level will occur at a given degree of slope.

The H.E. for 1° is represented by 1·50 inches, therefore
The H.E. " 2° " ·75 " &c., &c.

4. H.E. for 1° is 628 yards, represented by 1·50 inches, therefore
H.E. for 2° is 314 yards, represented by ·75 inches, &c., &c.

5. H.E. for 1° is represented by 1·8 inches, therefore
H.E. " 2° " ·9 " &c., &c.

6. H.E. for 1° is represented by 1·19 inches, &c., &c.
H.E. " 5° " 76·4 yards.
H.E. " 7° " 54·5 "
H.E. " 18° " 21·2 "

7. R.F. $\frac{1}{6336}$.
On map No. 1, H.E. for 1° is represented by 1·30 inches, &c., &c.
On map No. 2, H.E. for 1° is represented by 1·62 inches, &c., &c.

8. H.E. for 1° is represented by 2·25 inches, therefore
H.E. " 3° " ·75 " &c., &c.

9. Scales of H.E. are constructed by finding the H.E. in yards for a slope of 1° at a given V.I., and then finding the length on paper which represents that distance according to the scale of the map. The H.E. for a slope of 2° will be half that for 1°, and for 3° a third, and so on.
H.E. for 1° is represented by 1·62 inches, &c., &c.

10. H.E. for 1° is represented by 2·25 inches, therefore
H.E. " 3° " ·75 " &c., &c.

11. For explanation of the term "H.E.," see answer to 3.
For principle of construction of scales, see answer to 9.
For advantages of normal system, see answer to 17.

12. For principle of construction, see answer to 9. H.E. for 1° is represented by 1·30 inches, &c., &c.

13. H.E. for 1° is represented by 2·17 inches, therefore
H.E. " 2° " 1·08 " &c., &c.

14. H.E. for 1° is represented by 2·75 inches, &c., &c.

15. H.E. for 1° is represented by ·65 inches, therefore
H.E. " 3° " ·22 " &c., &c.

16. H.E. for 1° is represented by 1·12 inches, &c., &c.

17. The normal scale of H.E. is one by means of which the slope of the ground at any given place can be determined without reference to the scale of the map, provided that the contours have been drawn according to the normal system. This system is based on the convention that, when a scale of 6 inches to a mile is used, the vertical interval between the contours shall be 20 feet; and when the scale of 6 inches to 1 mile is departed from, the V.I. used shall be in inverse ratio to the scale adopted, thus :—

$$\text{new scale} : 6 :: 20 : x,$$

the fourth term of the proportion will give the *normal* V.I. to be used with the selected scale.

The advantages of this system are as follows :—

(1) The eye becomes accustomed to judge the distances between contours, which are always the same no matter what the scale of the map is, and consequently the slope can be sufficiently accurately gauged without the application of a scale of H.E.

(2) Any officer whose eye may not have been accustomed to judge the slopes can always ascertain them accurately by applying the scale of slopes on the service protractor.

(3) It saves the draughtsman the trouble of affixing a scale of H.E. to his sketch.

(4) The use of the normal system will give a sufficiently

faithful representation of the ground for tactical purposes (especially when working to the scales most commonly used) without overcrowding or confusion of contours.

(5) It is an immense advantage to have one uniform and universally recognised system of contouring throughout the service, especially as one officer's sketch may often have to be joined to that of another.

The scale is 10 inches to 1 mile. R.F. $\frac{1}{6336}$.

18. H.E. for 1° is represented by 1·35 inches, therefore
H.E. " 3° " ·45 " &c., &c.

19. The V.I. is 5 favn.
H.E. for 1° is represented by 1·5 inches, &c., &c.

20. The slope of the ground is 4°.
To make the scale of H.E., take a distance of $286 \cdot 5 \times 4$, or 1146 palms, off the scale attached. This distance will represent the H.E. for 1°; one-half that distance, or 573 palms, will represent 2°, and so on.

21. The R.F. of the map is $\frac{1}{12000}$.
H.E. for 1° is represented by 1·43 inches, &c., &c.

22. The V.I. is $13\frac{1}{3}$ feet.
H.E. for 1° is represented by 1·30 inches, &c., &c.

23. The correct V.I. is 22 feet.
H.E. for 1° is represented by ·86 inches, &c., &c.

24. H.E. for 1° is represented by 1·24 inches, &c., &c.

25. H.E. for 1° is represented by 2 inches, &c., &c.

26. $1\frac{1}{2}$°, $2\frac{1}{2}$°, 3°, 2°.

27. H.E. for 1° is represented by ·86 inches, &c., &c.

28. H.E. for 1° is represented by 1·14 inches, &c., &c.

29. H.E. for 1° is represented by 1·04 inches, &c., &c.

30. H.E. for 1° is represented by 1·52 inches, &c., &c.

GROUP VIII.

COPYING MAPS.

1. ·94 inch side.

2. ·71 inch side.

3. If an exact copy were required, squares of ·25 inch side should be ruled on the French map, and the paper for the copy prepared with the same number and arrangement of squares of ·315 inch side.

If the copy need not be very exact, any convenient multiple of these sides may be taken; for example, ·5 inch side for the squares on the original, and ·63 inch side for those on the copy, and so on.

The size of the square is determined by the amount of detail to be shown and the degree of exactitude required in copying. After the squares have been drawn the detail may be filled in square by square.

4. ·6 inch side.

5. R.F. $\frac{1}{40000}$. Sides $7\frac{1}{2}$ inches by 10 inches.

6. As the copy is to be drawn to the same scale as the original, the same sized squares should be drawn on both.

7. Prepare the original with squares of $2\frac{1}{4}$ inches side and

the copy with squares of $\frac{1}{4}$ inch side, or the original with squares of 3 inches side and the copy with squares of $\frac{1}{3}$ inch side.

8. ·59 inch side.

9. $\frac{3}{8}$ inch squares on the original and $\frac{1}{4}$ inch squares on the copy will be a convenient arrangement.

10. It will occupy a space of $1\frac{1}{2}$ inch by 1 inch.

11. I should adopt the method of copying by means of squares. The original and copy would first be prepared with squares (the same number and arrangement on each) the sides of which are in direct proportion to the scales of the original and copy.

When maps are copied for military purposes it will seldom be necessary to draw squares on either the original or copy of less than $\frac{1}{4}$ inch side. The size of the squares will depend upon the amount of detail to be copied and the amount of exactitude required.

Draw squares of 1 inch side on the original and $\frac{1}{4}$ inch side on the copy; but if a very exact copy is not necessary, then any convenient multiple of these measurements will do.

12. Draw squares of $\frac{1}{4}$ inch side on the original and ·47 inch on the copy, or squares of $\frac{1}{2}$ inch side on the original and ·94 inch on the copy, or squares of 1 inch side on the original and 1·89 inch on the copy, according to circumstances.

13. In the absence of any special instruments, such as a pentagraph, this operation is best done by means of squares, as described in answer to question 11.

14. Draw squares of $\frac{1}{4}$ inch side on the original and of ·792 inch side on the copy, or any convenient multiple of these sides may be used according to circumstances.

15. Draw squares of 1·42 inch side on the copy.

16. Squares of 1·26 inch side.

17. (1) By photography, (2) by the pentagraph, or (3) by the method of squares, which is fully described in answer to question 11.

18. Draw squares of $\frac{1}{4}$ inch side on the original and ·79 inch side on the copy, or any convenient multiple of these sides according to circumstances.

19. 1·218 inches.

20. R.F. $\frac{1}{4224}$.

21. When copied to four times the scale, the sides of the copy will measure 40 inches by 32 inches; the squares on the copy will have 1 inch side; the R.F. of the copy will be $\frac{1}{5280}$.

When copied to four times the area, the copy will measure 20 inches by 16 inches; the squares on the copy will have $\frac{1}{2}$ inch side; the R.F. of the copy will be $\frac{1}{10560}$.

22. When copied to one-ninth the scale, the sides of the copy will measure 2 inches by $2\frac{2}{3}$ inches; the squares on the copy will have $\frac{1}{4}$ inch side; the R.F. of the copy will be $\frac{1}{47520}$.

When copied to one-ninth of the area, the sides of the copy will measure 6 inches by 8 inches; the squares on the copy will have $\frac{3}{4}$ inch side; the R.F. of the copy will be $\frac{1}{15840}$.

23. The sides of the copy will measure $12\frac{1}{2}$ inches by 10 inches. R.F. $\frac{1}{12672}$.

24. 4·65 inches.

25. When copied to twice its scale, the sides of the copy will measure 32 inches by 18 inches; the squares on the copy will have 1 inch side; the R.F. will be $\frac{1}{7920}$.

When copied to twice its area, the sides of the copy will measure 22·627 inches by 12·728 inches; the squares on the copy will have ·707 inch side; the R.F. will be $\frac{1}{11200}$.

26. Squares of ·6 inch side should be drawn on the copy. As 9 is to 25.

27. 13·57 inches by 13·25 inches.

28. Squares of $\frac{1}{2}$ inch side should be drawn on the copy. The sides of the copy will measure 5 inches.

29. $7\frac{1}{2}$ inches by 5 inches.

30. Since the copy is to be fairly exact, squares of ·35 inch side should be drawn on the original and squares of ·25 inch side on the copy.

As the copy is also to be complete in all particulars, a scale of yards and also a scale of H.E. are required, because the V.I. is no longer normal. (See Plate II. fig. 1.)

31. The scale of the copy is in this case the same as that of the original, and contours 240, 300, and 360 are common to both scales. These contours should be copied in first, and the proper number interpolated according to the sketcher's idea of the general conformation of the ground. (See Plate XIII. fig. 1.)

32. See Plate XIII. fig. 2.

GROUP IX.

CONSTRUCTION AND DRAWING OF SECTIONS.

1. This is not a good example, as it is absurdly small. "Usual vertical intervals" may be taken to mean normal vertical intervals, which in this case is 10 feet.
The length of the section from A to H is $4\frac{1}{2}$ inches.
The section lines are ·068 inch apart.

2. The length of the section is 2·7 inches.
The section lines are ·136 of an inch apart.

3. The section lines are $\frac{3}{8}$ of an inch apart.
The length of the section is 4·36 inches.

AB,	gradient	$\frac{1}{5}$,	slope	$11\frac{1}{2}°$	nearly.
CD,	"	$\frac{1}{5\frac{1}{4}}$,	"	11°	"
DE,	"	$\frac{1}{3\frac{1}{7}}$,	"	18°	"
FG,	"	$\frac{1}{10}$,	"	$5\frac{3}{4}°$	"
AH,	"	$\frac{1}{15}$,	"	4°	"

4. The section lines should be ·17 of an inch apart.
The lowest line on the section should be marked 50 feet, the next 75, and so on up to A, which is on the line marked 225 feet. There should be eight lines altogether.

5. The section lines should be ·15 of an inch apart.
The length of the section is 5·45 inches.

6. The section lines should be $\frac{1}{5}$ of an inch apart.
The length of the section is 4·52 inches.

7. The section lines are $\frac{3}{11}$ of an inch apart.
The lowest line on the section should be marked 80 feet.

8. Assume the contours to be at the normal V.I.—*i.e.*, 20 feet.

The lowest line on your section will be the level of the second contour above the lake, because it is the next below the lowest contour touched by the section line.

The section lines will be ·136 of an inch apart.

9. Number of contours from the river up to A, commencing at 60 feet and rising 20 feet each contour to A, which is 260 feet.

The section lines are ·068 of an inch apart.

The lowest section line should be marked 40 feet.

10. Draw the section lines ·18 of an inch apart.

The length of the section is 4·95 inches.

Draw nine section lines, and let the point A be placed midway between the eighth and ninth lines and on the right-hand side of the section.

As the drop or rise is in each case 20 feet, all the other points will come midway between the section lines.

The lowest section line should be numbered 0, the next 20 feet, and so on to the highest, 160 feet.

The slope from C to D is $2\frac{3}{4}°$ nearly.
" " G to H " 2·83° "
" " H to I " $4\frac{1}{4}°$ "

11. The section lines should be drawn ·34 of an inch apart.

The lowest contour line should be marked 0, the next 50 feet, and so on.

The steepest gradient is the downward slope from the contour just below A to the next one; it is about $\frac{1}{25}$. (See Plate II. fig. 2.)

12. The section lines should be drawn ·136 of an inch apart.

The lowest line should be numbered 140 feet, the next 160 feet, and so on.

13. The section lines should be drawn ·136 of an inch apart.

The lowest line should be numbered 340 feet, the next 400 feet, and so on.

14. The section lines should be drawn ·113 of an inch apart.

The lowest contour should be numbered 350 feet, the next 400 feet, and so on.

15. The section lines should be drawn ·136 of an inch apart. (See Plate II. fig. 3.)

16. As nothing is said about the horizontal scale of the map, you may take it that the contours are at the normal V.I., and therefore the scale will be 6 inches to 1 mile.

The section lines should be ·113 of an inch apart.

The lowest lines should be numbered 220 feet, the next 240 feet, and so on.

17. ·227 of an inch apart.

18. ·39 of an inch apart.

19. 8 to 1.

20. R.F. $\frac{1}{8000}$, or 7·92 inches to 1 mile.

21. 5 to 1.

22. $\frac{1}{15026}$, probably meant to be $\frac{1}{15000}$.

23. 50 mètres.

24. The section lines should be drawn ·15 of an inch apart, and there should be six of them.

The length of the whole scale is 3·44 inches.

The lowest section line should be numbered 175 feet, the next 200 feet, and so on to the highest, 300 feet. (See Plate II. fig. 4.)

25. See Plate XV. fig. 1.

26. See Plate XV. fig. 2.

GROUP X.

FINDING THE NORMAL V.I. WHEN THE SCALE OF THE MAP IS GIVEN, AND *VICE VERSÂ*.

1. 15 inches to 1 mile.

2. 19·753 feet; say, $19\frac{3}{4}$ feet.
114·6 yards.

3. 60 feet, 12 feet, 180 feet, 75 feet, $22\frac{1}{2}$ feet, 35 feet, 45 feet, $7\frac{1}{2}$ feet.

4. 8 inches to 1 mile, or $\frac{1}{7920}$.
4·8 inches to 1 mile, or $\frac{1}{13200}$.
1·2 inches to 1 mile, or $\frac{1}{52800}$.
6·8571 inches to 1 mile, or $\frac{1}{9240}$.
$4\cdot\dot{3}\dot{6}$ inches to 1 mile, or $\frac{1}{14520}$.

5. $7\frac{1}{2}$ mètres, 4 mètres, $12\frac{1}{2}$ mètres, 25 mètres.

GROUP XI.

MAGNETIC VARIATIONS.

1. $15\frac{1}{2}°$ east.

2. Add 18° to each of the bearings taken, and plot the angles with reference to the true meridian lines.

3. Bearing of G from B is $232\frac{1}{2}°$.
" B from C is 292°.

4. Choose a level piece of ground, and on it prop up the rod so that it will rest at an angle of about 45° with the ground, the elevated end being pointed away from the sun. From the elevated end drop a plumb-line so arranged that the weight is just clear of the ground. With centre, a point immediately below the weight, and radius the distance from the centre to the extremity of the shadow of the stick, draw an arc on the ground from west towards east. This must be done some time before noon, say about 11 A.M. As the sun mounts higher and moves towards the west, the shadow will shorten and move towards the east. The shadow will lengthen again when the sun has crossed the meridian, and continue moving eastwards until it cuts the arc. Bisect the chord joining the two intersections of the shadow and the arc, then a line drawn through the centre and this bisection will give the direction of true north.

Take the bearing of this line. If the bearing reads less than 360°, the variation of the compass is easterly; and if it reads more than 0, it is westerly.

5. The "variation of the compass" is the angle which the magnetic meridian makes with the true meridian. It is not a constant quantity. It varies slightly to and fro during the course of twenty-four hours. It has also a comparatively steady and constant motion either towards or away from the

true meridian. At present it is approaching the direction of true north at the rate of about 7 minutes annually.

Its present variation (1896) is about 17° west, in the south of England.

The bearing from B to A will be 192°.

6. $16\frac{1}{2}$° west.

7. $7\frac{1}{2}$° east.

8. See answer to question 5; variation and declination are the same. For the last part of the question see answer to question 4, which explains how the variation may be found by day. If by night, proceed as follows. When "Zeta" of the Great Bear is in a perpendicular line either above or below the pole-star, then that star is in the true meridian, and the bearing of it being taken, the variation of the compass can be determined as before explained.

9. 202°.

10. A magnetic bearing is the angle formed by a line drawn from the observer to the object, and another line drawn from the observer in the direction of magnetic north. This angle is measured in degrees and parts of a degree, or in degrees and minutes.

The measurement always starts at magnetic north, and is continued round in the direction traversed by the hands of a watch.

A true bearing is the angle formed by a line drawn from the observer to the object, and another line from the observer towards the true north. This angle is measured in the same way as for a magnetic bearing.

The variation is 17° west.

The sun would bear 197° when on the meridian.

11. The card is graduated in degrees and half degrees, commencing at 0° at the south pole of the needle and read-

ing through west (90°) to north (180°) and east (270°) back to south (360° or 0°).

$17\frac{1}{2}$° east.

12. The variation would be 9° west.

13. If the conditions are favourable, the variation of the compass can be found by day, in the manner described in answer to question 4. If at night, the variation can be found by the pole-star, as explained in the latter part of the answer to question 8.

The bearing of the sun would be 190° 30′.

14. The correct variation is 18° east.

The margins of the map run 36° east of true north.

15. "Magnetic dip" is the tendency which the needle shows to dip its north end down towards the earth.

The needle would assume a horizontal position at the equator, and as it is brought northwards towards the pole the tendency to dip becomes more and more pronounced. This tendency is counteracted in the prismatic compass by weighting the southern semicircle of the card with sealing-wax.

For the remainder of the question see answers to questions 4 and 8.

16. (*a*) The variation is 14° 30′ east.
(*b*) " " 15° 30′ west.

17. The variation is 17° west.

18. The variation is 4° east.

19. The variation is 19° east.

20. The variation is 19° west.

21. The variation is 7° west.

22. The variation is 2° west.

23. The sun's bearing would be 352°.

24. The variation is 17° west.

25. The variation is 8° west.

GROUP XII.

CALCULATION OF HEIGHTS AND DISTANCES.

1. 99 feet.
20 miles $1466\frac{2}{3}$ yards.

2. 382 yards at 1° of slope. $54\frac{4}{7}$ yards at 7° of slope.

3. On embankment nearly 5 feet high.

4. B is 710 feet high, C is 960 feet high.

5. Distance of tower from object 43·4 yards. Height of tower $47\frac{8}{11}$ feet.

N.B.—If the correction is applied to these answers, the distance becomes 40 yards and the height 46·21 feet.

6. 20 feet.

7. "A gradient" is the ratio of the vertical distance between any two points in an inclined plane, to the horizontal distance between the same two points. This ratio is expressed as a fraction, the vertical distance being placed as numerator and the horizontal distance as denominator, both distances being always expressed in the same units of measurement.

The gradient from X to Y is $\frac{1}{22{\cdot}92}$

The distance from X to Y is $687\frac{2}{3}$ yards.

8. 100 feet.

9. 35·2 feet.

10. 458·4 yards, or, applying the correction, 459·17 yards.

GROUP XIII.

DETERMINATION OF HEIGHTS AND DISTANCES BY PLOTTING TO SCALE.

1. Distance from the house to the object 48 yards. Height of the house $55\frac{1}{2}$ feet.

2. $CA = 736$ feet, $CB = 197$ feet.
$A = 15°$, $B = 105°$, $C = 60°$.

3. D is 1586 yards from B.
DB makes an angle of 11° 45′ with the magnetic meridian and to the east of it.

4. 104 yards.

5. 431 yards.

6. HM is $1017\frac{1}{2}$ yards long; bearing 259°.

GROUP XIV.

DEFINITIONS.

1. *Watershed* is the line defining the highest part of a feature or chain of hills.

   Col is the neck joining the underfeature to the feature from which it springs.

   Underfeature is a feature springing from higher ground.

   Contour is the representation in plan of the line of intersection of a hill with a horizontal plane.

2. *Contour*, see above.

   Gradient, see answer to question 7, Group XII.

   Slope is the inclination, expressed in degrees, of a line inclined to the horizon.

   Horizontal equivalent is the horizontal distance in which a given difference of level will occur for a given degree of slope.

3. *Zero-line* is that line on a sketch to which all others are referred for their direction. For example, in a prismatic-compass sketch the zero-line is the magnetic meridian, and in a plane-table sketch, when no compass is used, it is the first line drawn.

   Back angle traversing is a method of traversing by taking each fresh forward direction with reference to the last line traversed. In other words, the sketch is set by the back station before determining the new forward direction.

   Meridian is a true north and south line.

   Saddle is a depression between two adjacent hills.

   Col, see answer to question 1.

   Datum-line is an assumed line with reference to which heights are shown on a section. It is the lowest line of the section, and (when no datum level is given)

is usually taken as the level of the contour immediately below the lowest contour cut by the line on which the section is made.

4. *Bearing*, see answer to question 10, Group XI.

Plotting is transferring to paper the bearings and measurements taken in the country.

A *traverse* is a sketch made by observing, measuring, and laying down to scale on paper the directions and lengths of a series of straight lines called "traverse lines," together with the positions of objects on both sides of these lines. The operation of making a sketch in this manner is called "traversing."

Forward angle is the direction from a point to the place the sketcher means to go to next.

Back angle is the direction or bearing from the sketcher's present position to the place he came from last. The back angle of any bearing can always be ascertained by adding or subtracting 180° to or from the observed bearing; thus the back bearing of 40° is 220°, and the back bearing of 320° is 140°.

Offset is a measurement taken at right angles from a traverse line to any object.

Contour, see answer to question 1.

Horizontal equivalent, see answer to question 2.

Meridian, see answer to question 3.

Magnetic meridian is a magnetic north and south line.

Saddle, see answer to question 3.

Watershed, see answer to question 1.

5. *Magnetic dip*, see answer to question 15, Group XI.

Magnetic variation, see answer to question 5, Group XI., and for manner of determining the magnetic variation see answers to questions 4 and 8, Group XI.

GROUP XV.

INSTRUMENTS.

1. (*a*) The card is graduated in degrees and half degrees.

(*b*) (*c*) The graduations start from the south end of the needle with zero, and increase through west 90°, north 180°, east 270°, and back again to south 360° or zero. The reason for this is that when looking towards the north the south end of the needle is under the eye, and consequently the reading should be zero. The same is true for all points.

(*d*) The magnetic variation of every compass should be known, so that the direction of true north may be accurately shown on all sketches. This direction is required for purposes of comparison with, or fitting to, other sketches or maps, since it forms a constant and invariable direction common to all.

(*e*) All compasses differ slightly in the amount of their variations, and many differ a great deal; therefore it is necessary that a sketch, to be correct, should be begun and finished with one and the same compass.

2. The prismatic compass is—

(*a*) More portable.

(*b*) A better instrument to use when traversing, because an error once made does not go on increasing as it would do if a similar error was made when traversing with the plane-table (used without the box-compass).

(*c*) The operation of "resection," so necessary in all sketching, can be performed by the use of two points only, whereas three are required when working with the plane-table (without the box-compass).

(*d*) Better fitted for hasty or secret work.

(*e*) More convenient for use in close and intersected country, as a bearing may be taken on a place where a plane-table could not be put up.

The plane-table is—

(*a*) Simpler to use.

(*b*) More accurate, especially in stormy weather.

(*c*) More convenient and comfortable to work with.

(*d*) Not subject to local or atmospheric influences.

(*e*) It engenders a habit of continually comparing the sketch with the ground, and thus teaches the sketcher to become a good judger of distance.

(*f*) Quicker in operation.

3. See answer to question 1.

4. For first part of this question see answer to question 2.

The angular measurements taken with the prismatic compass are more liable to error than those taken with the plane-table sight-vane, because—

(1) It is difficult to hold the compass steady enough to get correct bearings, especially in a high wind.

(2) The compass-card may not be properly centred.

(3) There is always the possibility of reading the bearing incorrectly.

(4) The observed bearing has to be remembered while you put away the compass, get the protractor and adjust it to the sketch.

(5) The protractor may not be properly placed—*i.e.*, its long edges may not be correctly parallel to the magnetic meridian of the sketch.

(6) The wrong bearing may be plotted from the protractor.

(7) The compass may without your knowledge have been subject to some local disturbing influence when you took the bearing.

With the plane-table each and all of these possible sources of error are eliminated, since there is nothing to read and remember, nothing to plot, and local disturbances or faults in construction do not interfere with its accuracy.

5. The index error of a clinometer is the misplacement of the zero.

To find the amount of index error, proceed as follows: Place two sticks of convenient height, one at the top and the other lower down a slope. Resting the clinometer on the top of the upper stick, take the angle of depression to the top of the lower one, say this reads 4°. Now go to the lower stick and take the angle of elevation to the top of the upper one. If this also reads 4° then there is no index error; but if, on the other hand, it reads 3°, then the zero misplacement is $\frac{1}{2}$°.

In using a clinometer with an index error such as the above, it is necessary, in order to get correct results, that $\frac{1}{2}$° should be deducted from all angles of depression, and a like amount added to all angles of elevation, observed with the instrument.

6. Set the cylinder to zero. Press the sliding-collar back to 6 on the scale, look through the eye-hole at any sharply defined vertical object. If the reflected portion of this object coincides with the portion seen directly, the instrument is in adjustment.

GROUP XVI.

CONVENTIONAL SIGNS. (SEE PLATE III.)

The authorised conventional signs are republished in Plate III. by the courteous permission of the Controller, Her Majesty's Stationery Office.

GROUP XVII.

PLOTTING FROM FIELD-BOOKS, FIELD-NOTES, ETC.

1. DA is 159 yards long.
The bearing from D to A is $277\frac{1}{3}°$.

2. From X to the spire is 926 yards.
From the spire to X the bearing is 240°.

3. Check your triangulation as follows :—
C to G should bear 100° and be 1412 yards long.
BF is 766 yards and BC 787 yards long.

4. GA is 283 yards long and bears $288\frac{1}{2}°$.

5 Check your intersections as follows :—
BX=456 yards, BF=1122 yards, BG=1087 yards.
BC=1056 yards, BD=719 yards, BE=522 yards.
R.F. $\frac{1}{7920}$.

Draw a line making an angle of 5° to the east of the magnetic north line, and mark it with the proper sign for true north.

6. See Plate IV. fig. 1. AE=951 yards, AD=881 yards.

7. From I. to III. is 681 yards, from I. to IV. is 552 yards, from I. to V. is 1124 yards, from A to B is 1090 yards.
Scale, 5·965 inches will represent 1500 yards. R.F. $\frac{1}{9051.43}$.

8. From W, Z bears $78\frac{1}{2}°$, distance 1066 yards.

9. ABC forms an equilateral triangle of 900 yards sides.
C is 471 feet above A and 330 feet above B.

10. 170° and 200°.

11. Take your measurements off the 40 scale. One division on the 40 (natural scale) represents 1 yard.

From ⊙ I. to ⊙ V. in a straight line is 230 yards.

12. Check your work as follows :—

⊙ II. to ⊙ IV. 1620 yards, ⊙ II. to ⊙ V. 1905 yards, ⊙ I. to ⊙ V. 2563 yards, ⊙ I. to ⊙ VI. 164 yards, ⊙ II. to chimney 760 yards.

13. From station I. to station IV. is 762 yards.

Bearing of station I. from station IV. is $264\frac{1}{4}$°.

14. Check your working as follows :—

DA=618 yards, AE=824 yards, AC=1184 yards.

It is not a satisfactory method of determining the position of E, because the angle of intersection is too acute, being only $27\frac{1}{2}$°.

15. Check your working as follows :—

BC=447 yards, BD=397 yards, DC=603 yards.

16. Check the distances as follows :—

AD=685 yards, AG=950 yards, AF=694 yards, AE=489 yards, AC=358 yards, FH=402 yards.

(*a*) The intersection at D is bad, the intersecting angle being only 39°. That at F is also not good, the angle being $48\frac{1}{2}$°. The angle at E is 54°, which is too small for a good intersection.

(*b*) The accuracy of the intersections at the three points objected to could be tested by taking bearings to them from other points; for instance, D might be more accurately fixed from G or C, F from G, and so on: or the lineal test could be applied; for example, D could be fixed by pacing its distance from B along the observed line BD.

(*c*) BE would form a good supplementary base for the extension required.

(*d*) The bearing of E from B is 190° 30′, therefore the bearing of B from E is 10° 30′.

(*e*) Go down the slope until you can see both A and K, and place yourself in a straight line between these two points. Now take the bearing of K; the reading will of course be the same as if taken from A.

(*f*) Take a check bearing to K from F and to G from D.

17. AD = 693 yards

Note.—When plotting the bearings in this question take no notice of the words "B is due magnetic north." This phrase is totally unnecessary, besides being slightly wrong.

18. Check the distances as follows:—

BE = 715 yards, BF = 1547 yards, BD = 561 yards, and BC = 667 yards.

Draw at any convenient place on your paper a line parallel to the magnetic meridian, draw another line 13° to the west of it, mark the former with the proper sign for magnetic and the latter for true north.

19. Check as follows:—

⊙ I. to ⊙ III. 402 yards.

⊙ III. to ⊙ V. 307 yards.

⊙ V. to ⊙ I., distance 657 yards, bearing 209°.

20. The closing distance should be 390 yards, and not 385 as stated.

Distance from ⊙ I. to ⊙ III. is 848 yards.

21. (*a*) The points L and H.

(*b*) Yes, to the point K, because the intersecting lines from A and B form an angle at K too acute to make the position of that point very reliable. K can, however, be accurately fixed from H.

(*c*) The distance EH is 1560 yards, and LD 1870 yards.

22. AD=784 yards, AX=769 yards, AH=587 yards, AY=860 yards, AC=776 yards, AZ=1244 yards.

23. Apply the following checks:—
AC=1822 yards, CE=1031 yards, AE=2340 yards.
Bearing of A from E is $189\frac{1}{4}°$.

24. Distance D to F=1710 yards.

25. Check as follows:—
AE=1449 yards, AD=918 yards, ED=1618 yards, AX=1510 yards.

26. Select a scale—say, 1 inch to 1 mile.
Check as follows:—
BX=6·54 inches or 11,510 yards.
BY=4·667 inches or 9214 yards.
YX=3·4576 inches or 6085 yards.
Bearing of X from Y is 127° 45′.

27. Check as follows:—
AC=1481 yards, CE=1293 yards, AE=2763 yards.
Bearing from A to E is 358° 36′.

28. Check as follows:—
AC=250 yards, CE=305 yards, AE=482 yards, EF=320 yards, AF=390 yards, AG=320 yards, and the bearing GA is 0° or 360°.

29. Check as follows:—
AE=860 yards, AD=956 yards, AC=510 yards, AK=380 yards, AF=787 yards, AX=844 yards, AH=887 yards, XG=417 yards.

Exception is taken to the fixing of E, because the angle of intersection at that point is too acute; and also to K, because its angle of intersection is too obtuse, these angles being $17\frac{1}{2}°$ and 150° respectively.

The position of E can be checked from H, and K from C.

The intersecting angle at D being $43\frac{1}{2}°$, is too acute to give a very reliable intersection.

30. Check as follows :—

AD=1169 yards, AC=1087 yards, AE=1463 yards, AK=1100 yards, DC=2036 yards, DG=1531 yards, DF=1635 yards, DL=2755 yards.

Bearing of L from D=295° 45′.

The point K is badly fixed, because the angle of intersection being only $17\frac{1}{2}°$ is much too acute.

The angle at E being $48\frac{1}{2}°$, does not give a very reliable intersection.

The angles at C and D are both slightly less than 60°, and may therefore be called "fair angles of intersection" only.

GROUP XVIII.

KEEPING FIELD-BOOKS.

1. See Plate IV. fig. 2.

2. See Plate IV. fig. 3.

3. See Plate V. fig. 1.

4. The answer to this question is given fully, but the student may condense it as much as he thinks necessary.

(1) Rule two lines down the centre of the last unused page of the field-book.

(2) Begin the traverse at some accurately fixed point on your sketch—that is, if the object of the traverse is to fill in the details of a sketch. If, on the other hand, you are making an independent traverse, you may commence at any convenient place on your paper, taking care that this point

is chosen and the meridians drawn so that the whole of the road will come on to the paper.

(3) From this point, called ⊙ I., take bearings, first to the place you are going to next (forward bearing), and then to any other points you may require.

(4) If contours are to be shown, the height of the starting-point should be known, found or assumed according to circumstances, and the angles of elevation or depression to the several points found and noted.

(5) Draw a line across the chain column at the bottom of the page of the field-book, and above this line put the sign ⊙ I.; above this put in figures the first forward bearing, and put the sign for degrees to it, thus, 27° or $58\frac{1}{2}$°.

(6) Stand facing station II., and in the offset columns draw dotted lines right and left of the chain column roughly in the direction of the objects to which you have taken bearings. Write on these lines the objects and the bearings, thus—to church 127°.

(7) Note the distance in yards from your position to each side of the road, and write these distances on their respective sides of the chain column. If the road is fenced draw continuous lines, and if unfenced dotted lines, roughly about $\frac{1}{5}$ of an inch on each side of the chain column, to represent the sides of the road. Put all measurements of the breadth of the road outside the chain column and inside these lines.

(8) Now pace towards ⊙ II., selecting some mechanical way of remembering the number of hundreds of yards paced. If contours are to be shown, stop at the proper H.E. according to the degree of slope, and put in the contour right and left.

Always write the distance from your last station down *at once* in the chain column whenever you stop to make an observation which is to be recorded, and be careful when you begin pacing forward again that you commence counting *where you left off;* the distances from ⊙ to ⊙ are always continuous.

(9) If you want to show objects near the traverse line stop when you are opposite to them—*i.e.*, when a line from you

to the object would be at right angles to the traverse line. Judge the distance to the object, or, if necessary, pace it; but in this latter case take care to leave a mark on your traverse line to show where you left it. These lines at right angles to your traverse line are called "offsets"; they are put in as dotted lines in the field-book.

This system of fixing the positions of objects near the traverse line by means of offsets saves a great deal of time and labour, as otherwise the positions would require to be fixed by bearings.

(10) All distances measured along an offset are continuous, like those from ⊙ to ⊙.

(11) When measuring an offset, it may sometimes be necessary to leave it to measure a distance to some object right or left. This departure is called a "secondary offset," and is always at right angles to the first or primary offset.

(12) Where a hedge, fence, or other object crosses the traverse line obliquely, it should join and leave the chain column at points immediately opposite to one another.

(13) On arrival at ⊙ II. the total length of the first traverse line is entered, and a line drawn across the chain column above the entry.

(14) Whenever possible, take check-bearings to any points the positions of which are fixed.

(15) Fix by intersection from ⊙ II. the positions of all suitable points to which you have previously taken bearings, and make the corresponding entries in the field-book, taking care to keep your back to ⊙ I. when doing so, in order that these entries shall be made on the right or left of the chain column as they occur.

(16) Proceed from ⊙ II. in the same manner as from a fresh starting-point.

(17) As all measurements along an offset and in the chain column are inclusive, it is necessary, when you wish to show a measurement which is not to be included, to enclose it between arrow-heads thus, < 45 >.

(18) It will be seen from the above that no entries are made in the chain column except the stations and their num-

bers, the forward bearings and the distances from the station to the places where a halt was made for an observation entailing an entry.

(19) All traverse lines should be as long as possible, and therefore when the road winds very much it will be better, if possible, to take one long traverse line off the road and put in the bends by offsets, than to take a series of short lines along the road itself.

5. See last answer.

6. See paragraph 18 in answer to question 4.

7. See Plate V. fig. 2.

8. Make this field-book in the same way as shown in Plate IV. fig. 3, or Plate V. fig. 1.

Start ⊙ I. at *c*, and take your first traverse line on the north side of the road from *c* to the place where the road disappears from view over the spur about 150 yards beyond the letter *d*. Put in the road by offsets.

Take ⊙ III. in a straight line from ⊙ II. about 660 yards long, and again put in the road by offsets.

Take ⊙ IV. at *e*, and so on.

9. See Plate V. fig. 3.

GROUP XIX.

TRAVERSING.

1. I should prefer to work by the compass for the following reasons :—

(1) As it is imperative that the plane-table should be "set" at each station, it would be necessary to leave a mark

at every station when working without the box-compass; and as under the circumstances each traverse line would be short, a waste of time would result—first, in selecting and arranging the back-station mark, and second, in setting the table so often.

(2) If I made an error in setting the table or in laying off the new forward direction, that error would not only be perpetuated throughout the remainder of my work, but would actually go on increasing; whereas if I set the table each time by the compass, a similar error once made would certainly be perpetuated but would not increase.

2. Traversing with the plane-table is performed thus:—

(1) Put up the table over the spot where the traverse is to begin.

(2) Turn the board so that the paper will contain the whole traverse.

(3) Roughly level the board.

(4) Clamp it.

(5) Place the box-compass on one of the corners of the paper, and turn the compass without moving the board until the needle lies parallel to the sides of the box.

(6) Rule a line on the paper along one of the sides of the box, and mark with an arrow-head the north end of it.

(7) Select a point on the paper to represent your present position, and stick the pin upright in that point.

(8) Pivoting one edge of the ruler against the pin and looking through the raised sights, direct the ruler on the next forward station, then draw a line from the pin along the edge of the ruler in the direction of that station.

(9) Still pivoting the ruler on the pin, obtain the directions of any other points you may require.

(10) Adjust the ruler once more to the first traverse line and look through the sights: if they still point to station II., you prove that the board has not been accidentally moved from its original position.

(11) Unclamp the table, take it up and carry it to station II., measuring the distance as you go.

(12) Put the table up at station II. and mark off the distance according to scale, then stick the pin in the point representing station II.

(13) Level the table as before.

(14) Adjust the ruler carefully to the first traverse line on the sketch, and turn the board with the ruler on it until the sights are directed on station I. The board is now set.

(15) Clamp the board carefully, and again look through the sights to see that the board has not moved during the operation of clamping.

(16) The box-compass may now be placed with a long edge coincident with the N. and S. line, and if the needle lies correctly you know that your board is rightly set.

N.B.—Either one or other of the operations described in (15) or (16) must be done; it is seldom necessary to do both.

(17) Pivoting the ruler on the pin, take the next forward direction to station III., and draw a line towards it.

(18) Intersect any convenient and suitable points to which rays have previously been taken.

(19) Adjust the ruler again on the new forward direction, and see that the board has not moved.

(20) Unclamp the board and move to station III., and so on.

N.B.—When the traverse line is short, it will be found useful to make check-dots in prolongation of the line; these will assist you in adjusting the ruler on the line when setting the board.

The sketch showing three stations is shown in fig. 4, Plate V. In this figure A represents the position of the plane-table when it is first put up over the point A on the ground. The position of A is then selected on the paper at *a*, and the forward direction to B is drawn in, as well as lines of direction to tree T and church D. The table is then taken to B, the distance AB set off to scale, and the table set by the back-station. The positions of T and D are now intersected and fixed on the paper, and the new forward direction

to C laid down. On arrival at C, the distance BC is laid off to scale.

For the advantages of the plane-table, see the latter part of the answer to question 2, Group XV., Instruments.

GROUP XX.

SELECTION OF BASE AND INTERSECTION OF STATIONS.

1. The most compact form in which a survey of this extent could be drawn would be that of a square of 12·649, or, say, 12·65 inches side; or a rectangle may be drawn of such a size that the enclosed space will be 160 square inches.

Draw a square or rectangle of the size required; choose a central position for the base, making it a line of about 3 inches long.

Intersect other points from the ends of the base, choosing those points so that the intersecting lines shall not be either much longer or much shorter than the base; then the intersecting angles will be neither too acute nor too obtuse—*i.e.*, not less than 60° nor more than 120°. From the ends of the base take bearings or rays to other and more distant points, or to points nearly in prolongation of the base, with a view to intersecting them later when a favourable opportunity offers.

Note.—The extent of ground mentioned in this question is so great that it would require a piece of paper as large as a double sheet of foolscap for its representation at the scale mentioned. I suppose I misread the question; if so, I am apparently in sympathy with many of the competitors, for the following appears in the Examiner's report: "Question 2 was the worst answered, from the fact that so many of the candidates misread it." I do not think an examiner has any right to set a very obscure question in an examination on which the whole future of a competitor's life may depend. I can imagine some of the candidates struggling hard to represent 10 square miles of country on a sheet of paper of about half the requisite size, wasting valuable time which

might have been more profitably spent on answers to questions which were not so liable to be misread.

I confess also to my inability to answer the remainder of the question, "why . . . the extent of ground is mentioned." The only answer which suggests itself to me is that it was mentioned in order to mislead the candidates, which it seems to have done most successfully. It could not have any effect on the base, because have we not the text-book authority for saying that "for most military sketches a base of from 600 to 1200 yards is sufficient"? nor could it affect the distance apart of stations, because the same authority says that "stations are convenient about 2 or 3 inches apart on the plan." It would of course affect the *number* of stations, but how was a candidate to represent that *on a diagram* without drawing the margins enclosing the extent of ground stated? It would be very interesting to hear the proper reading of this question.

2. Select a base of about 3 inches long. Along the road from E towards D would be a good place, because it is central, free from obstacles, flat, and a good view of the surrounding country can be got from both ends (if the road fences do not interfere).

From the ends of this base draw lines to selected points on each side of the base. Choose these points anywhere most convenient for your purpose, being careful (1) that the points chosen are visible from the point of observation—for instance, do not take N or T from E—and (2) that the points chosen at one end of the base for intersection at the other end shall form "well-conditioned triangles."

The bearing of R from S is 281°
" R from N is $188\frac{1}{2}$°

It is not possible to get these bearings very exactly, because the points are so badly defined.

The position of the bridge could be fixed by resection from R and M, which would give a good angle of resection, and M being a house, would be high enough to be visible. Get the bearings of those two points from the bridge, and plot the back angles from M and R respectively.

3. Choose a base of about 3 inches long on the left bank of the Gorsham Brook, and on the flat ground, say between

the 80- and 100-feet contours, and roughly parallel to these contours.

From the left-hand end of the base take bearings to A, B, Y, and some other points not so far off which can be suitably intersected from the other end of the base.

From the right-hand end of the base intersect the chosen points, and also take bearings to X, T, M, N, and K.

Extend your intersections in this way all over the map, and seize every favourable opportunity to fix the required points.

4. (1) "The number of stations chiefly depends on the scale of the survey." (This is a quotation from the text-book : see note to this answer.)

(2) The distance apart in plan should be from 2 to 3 inches.

(3) The distance apart on the ground will depend on the scale : the smaller the scale, the further apart should the stations be.

(4) Their relative positions should be such as to give good angles of intersection, and form "well-conditioned" triangles with the points from which they were intersected.

Note.—I cannot see why the number of stations depends on the scale, because if I make a plan of a piece of ground which, when completed, will occupy a space of, say, 36 square inches, the number of stations will be roughly the same whatever the scale of the map may be. If stations are to be about 2 to 3 inches apart on plan, it follows that only a certain number can be got into a plan of a given size, and the scale has nothing to do with it.

Certainly it is true that the larger the scale on which any *given area* of country is to be represented, the greater will be the number of stations required; but why? surely not on account of the scale, but because the size of the plan is greater. It would therefore seem more correct to say that the number of stations would depend chiefly on the size or area of the plan.

5. (1) Central position. (2) Level as possible. (3) Free from obstacles. (4) Good view of surrounding country from both ends.

Acute and obtuse intersections are a source of error, be-

cause (1) it is not easy to locate with exactitude the point of junction of two lines forming such an intersection, and (2) if an error was made in the direction of one of the intersecting lines, the position of the point found will differ very materially from its true position.

6. See last answer for rules.

About $\frac{1}{2}$ to $\frac{3}{4}$ of a mile on the ground.

7. From about 600 yards to about 1200 yards in length. Use a subsidiary base.

8. For general rules see answer to question 5.

About 500 to 700 yards apart.

Check-bearings are taken from some point the position of which it is required to verify, to some other accurately fixed point. If the back-bearing is then plotted from the fixed point, the line should pass through the observer's position, and if it does not some error exists.

9. Points nearly in prolongation of a base are fixed by taking bearings to them from one of the ends of the base and intersecting from other points when a good oppportunity offers.

"Satellite station" is a term used in surveying with a theodolite. It means the position near a station where the theodolite is set up because the station itself is inaccessible.

10. The length of the base required is about 3 inches. A satisfactory base of that length cannot be got near the centre, but it could be got near the top of the map on either side of the river, if the road fences would not interfere with its accurate measurement. On the whole, however, it would be preferable to take a smaller base near the centre and expand it by means of a subsidiary base. A suitable position for a primary base of that kind could be found stretching from near *c* along the road towards *f*.

11. See answers to questions 5, 2, and 4.

12. The best base would be a line joining the tops of the two knolls immediately to the south of the valley in which the river flows. If the slopes of the ground between these two points are considered to interfere with the accurate measurement of the ground, then a smaller base may be selected astride of the col between these two knolls, and the positions of the knolls fixed by intersections from each end of the base.

13. Take AB for the base.

From A take bearings to D, E, and I. From B take bearings to E, H, and I.

I is well intersected and E fairly so.

Now move from B to E, measuring the distance as you go, as a check to the position of E.

From E take bearings to F, G, H, C, and D. Now go to I and intersect F, G, and C. Now move to C, applying the "linear test"—*i.e.*, measuring the distance on the ground to see if it corresponds with the plan distance—and from C check your position from D and intersect H.

GROUP XXI.

CONTOURING.

1. See Plate VI. fig. 1.

2. See Plate VI. fig. 2.

3. See Plate VI. fig. 3.

The alterations recommended in the note to this question have been carried out in the figure.

XC = 464 yards, XA = 506 yards, AB = 219 yards, BC = 334 yards.

4. See Plate VII. fig. 1. The heights asked for will be found on the figure.

5. See Plate VII. fig. 2.

6. See Plate VII. fig. 3.

The alterations in this question recommended in the note have been carried out in the figure.

The distances are as follows: AG=272 yards, AD=554 yards, AC=444 yards, AF=1189 yards, AH=584 yards, AE=920 yards, BF=254 yards, BD=1097 yards, BE=976 yards, BH=832 yards, DG=569 yards.

7. XT=955 yards, XS=795 yards, YT=926 yards, YS=944 yards.

Calculated from X, the height of T is	275	feet.
" " Y, " " T "	294	"
Average . .	285	"
Calculated from X, the height of S is	250	"
" " Y, " " S "	248	"
Average . .	249	"

The height of Y above X is 100 feet.

" " T above S is 36 feet. The bearing of T from S is 356°.

See Plate VII. fig. 4.

8. Let us suppose that the details of the sketch, including rivers, roads, villages, farms, woods, &c., have been put in, and all that remains is to fill in the contours.

If during the course of construction of the sketch you have come across a bench mark or other indication of the height of any point on the sketch above sea-level, then fix the position of this point by resection (if its position is not already marked), measure the distance from the top of the hill from whence you intend to commence contouring, take

the angle of elevation or depression, and find the height by calculation. If no indication of the heights above sea-level can be found, then it will be sufficient to assume the height of the hill at anything you choose.

Now get in your first contour line all round the hill, or as far as it is necessary to go, at the same time noting and laying down the directions and slopes of all the spurs and watercourses. Select a section line—this is generally one of the most prominent spurs—find and plot its direction on the sketch, take its angle of depression with the clinometer, and refer to your protractor or calculate the proper H.E. for each contour at that degree of slope. Pace down the section line, stop at each contour and sketch it in on each side of you. Contours can in this way be drawn in for a long distance on each side of the observer; for as the directions of spurs and watercourses have previously been laid down, you can by means of the clinometer determine points on these features which are on the level of the ground on which you stand, and the contours can be made to pass through these points, their direction being found by the compass if necessary.

When you come to a decided change of slope, stop, draw in a "form line," find how many feet you have fallen from the last contour, ascertain the new slope, and continue pacing down until you have fallen the required number of feet to make up the correct V.I. from the last contour.

If the direction of the spur changes, find the new bearing by the compass, or by recognising its direction with regard to some object already fixed on the sketch. It will greatly help, especially when the survey is extensive, to stop on contours now and then and note for "reference points" those points on the other side of the valley or on other spurs, &c., which are on the same level as yourself.

When you approach an underfeature, stop when you get on the same level as its top, note that height, and then continue pacing to the col. Surmount the knoll and start again on the other side: you know the height, and the contours round the knoll can be put in at once.

It would also be of great assistance if, when at the top of the hill, angles of depression had been taken to different points fixed on your sketch, because the heights of these could be found at once by calculation and noted on the sketch.

9. These features can all be found on the Plate of Conventional Signs (Plate III.)

For latter part of the question see last answer.

10. AF=605 yards, AW=441 yards, BF=556 yards, BW=546 yards.

Take B as any convenient height, say 100 feet.

Then A=163 feet. See fig. 1, Plate VIII.

F calculated from A is	321	feet.
F " " B "	304	"
Average . .	312	"
W calculated from A is	278	"
W " " B "	271	"
Average . .	274	"

The command of F over W is 38 feet.
" " F " B " 212 "
" " W " B " 174 "

The value of the angle at F is 62°, and at W 74°.

11. See Plate VIII. fig. 2.

12. AC=566 yards, BC=1110 yards.

See Plate VIII. fig. 3.

13. See Plate IX. fig. 1.

The examiner evidently meant the river from E to F to pass between the points A and G, which in the question he calls "the base." It should, however, be pointed out that the river would form a serious obstacle to the measurement

of the base, not alone on its own account but because of the slopes which must be given from the high ground at A and G down to the river's course. We must therefore suppose that the distance AG has been determined in some other way than that of actual measurement on the ground.

The distances are as follows :—

AH=543 yards, AF=858 yards, AD=338 yards, AB=885 yards, AC=620 yards, AE=342 yards.

In the plate the height of F has been assumed at 150 feet above datum.

14. See Plate IX. fig. 2.

The distances are as follows :—

From A to source of stream			337 yards.
"	mouth	"	687 yards.
From B to source		"	256 yards.
"	mouth	"	382 yards.

The heights of these points are marked in the figure.

15. XS = 612 yards, XM = 732 yards, XB = 655 yards, XA=605 yards, XC=760 yards, XP=936 yards, XY=564 yards, MZ=408 yards.

Height of X is 278 feet.

See Plate IX. fig. 3.

16. See Plate X. fig. 1.

As the contours are not normal, it is necessary to draw a scale of H.E.

17. See Plate X. fig. 2.

18. See Plate XI. fig. 1.

19. See Plate IX. fig. 4.

The distance CE is 585 yards.

The angle of elevation from C to D is about $7\frac{1}{2}°$.

The gradient from X to E is about $\frac{1}{128}$.

E is not visible from either A or D, because the slopes

from these two points towards E are gentle at first and steeper afterwards, forming a convex section.

20. See Plate XII. fig. 1.

AC=776 yards, AD=404 yards, AH=867 yards, AF=591 yards, AE=445 yards, BC=450 yards.

From C to F the bearing is 231° and distance 1061 yards.

Some of the intersections are not possible, because the points are not visible from one another; for instance, C and D are not visible, and therefore could not be intersected from B.

21. See Plate X. fig. 3.

If the student finds any difficulty in contouring the spur, he should draw a rough section first.

22. AC and AE each equal 992 yards. AD is 1146 yards, BH=404 yards, CG=430 yards, AF=525 yards.

See Plate XI. fig. 2.

23. See Plate XII. fig. 2.

As the V.I. is not normal, it is necessary to attach a scale of horizontal equivalents.

GROUP XXII.

MAP-READING.

1. A, D, and F are all 250 feet above the lowest contour; G and C come next, height 200 feet each; B, E, and K come next, height 150 feet each.

2. Starting from the river on the right-hand vertical margin of the map, and proceeding towards the top, the following contours cut the margin: 0, 15, 30, 45, 60, 75, 90,

105, 120, 135, 135, 135, 150, 165, 180, 195, 195, 180, 165, 150, 135, 120, 105, and so on round the map.

195 feet is the level of the highest contour on the map, and the highest point lies probably midway between the two 195-feet contours on the right-hand margin.

3. By the watercourses. The lowest contour on the diagram is the last one the rivers cross near the top of the map. The height of A is 105 feet

4. The contour marked 60 is the lowest, and that round A is the highest. Number the contours from 60 to 260 feet, increasing the height by 20 feet at each successive contour.

5. The gradient of ascent from *a* to the next contour is $\frac{1}{8}$; from thence to the point where the road *touches* the next contour is $\frac{1}{38}$. After this point the road is fairly level until it begins to ascend again where this same contour crosses it: the gradient from that point to the next contour is about $\frac{1}{36}$, to the next $\frac{1}{24}$, and $\frac{1}{14}$ up to the contour near *b*.

The elevation from *a* to D is about 3·35°.

6. The V.I. is 25 feet.

GROUP XXIII.

EYE-SKETCHING.

1. In the same manner as traversing with the plane-table without the box-compass.

The sketch has to be set before each operation or series of observations from one point, by means of the back-station or with reference to surrounding objects already fixed.

As there is no ruler provided with sight-vanes, lines are taken with a straight-edge of any kind, the sketch being

laid flat on the ground and the straight-edge directed on the distant object either by looking along the edge, or, as will probably be more convenient, by placing its edge in the same vertical plane as the distant object by means of a plumb-line or a pencil held vertically. This operation being repeated at other points, the positions of the observed points are fixed by intersection.

2. First set the sketch by the back-station, then without moving the paper adjust the ruler so that its edge, whilst touching the point on the paper representing your position B, is also directed on the next station C.

The manner of aligning the ruler is explained in the last answer.

During the operation of "setting" the paper should be moved and the ruler kept steady in its position on the line AB on the sketch; but when taking the direction of C the ruler is moved round B as a pivot, and the paper kept steady.

3. See answer to question 1.

The advantage of eye-sketching is, that it enables a practised surveyor to turn out a very fairly correct sketch when no instruments are available.

The disadvantages are—

(1) The process necessarily requires much time, care, and forethought.

(2) Resection is a more lengthy and less reliable operation.

(3) If the country is much enclosed, or for any other reason the view is restricted, sketching without instruments becomes very arduous and inaccurate.

4. See answer to question 1.

5. This operation has now been eliminated from the text-book.

The north point can be fixed in a much more reliable manner by marking on the sketch the line of the shadow of

a plumb-line at twelve o'clock, *taking care that the sketch is accurately set before doing this.* If the time shown by your watch is correct mean time, the error in the direction of the north and south line will not much exceed 4° at any time of the year.

6. See last answer.

7. See answer to question 1.

8. To make an intersected eye-sketch it will be necessary to choose, measure, and lay down a base, from the ends of which observations are made to other points in the surrounding country whose positions can be afterwards fixed from the other end of the base in the same manner as an intersected sketch would be made with a plane-table without using a box-compass. The manner of making the observations is explained in answers to questions 1 and 2 of this group.

GROUP XXIV.

FINDING POSITION BY RESECTION OR OTHERWISE.

1. (a) *With the magnetic needle.*

Place the long edge of the compass-box coincident with the north and south line marked on the sketch, then turn the board without moving the compass until the needle lies parallel to the sides of the box. The table is now set. Stick the pin into one of the points on the sketch, and pivoting the ruler on the pin, turn it without moving the board until the sights are directed on the corresponding point in the country, then draw a line from the pin towards yourself. Do the same with regard to another of the points, choosing that one which will give you the best angle of intersection.

The point of intersection of these two lines will mark your position.

N.B.—Be careful that the table does not move from its "set" position during the whole of this operation.

(b) *With the plane-table sight-vane only, and without the magnetic needle.*

There are two ways of finding an observer's position without the aid of the magnetic needle—viz., the method of adjustment and the three-point problem; but as the former requires the use of transparent paper in addition to the sight-vane, it is evident that the latter operation is what the examiner wanted.

Suppose the three points in the country are A, B, and C, and their representations on the sketch are *a*, *b*, and *c*. By means of the ruler align *bc* on C, and from *b* draw a line towards A; now align *cb* on B, and from *c* draw a line towards A; call the point where these two lines intersect *x*. Align *xa* on A, and the sketch is set.

Clamp the board in this position, and resect your position from B and C in the usual manner.

Note.—The three lines B*b*, A*x*, C*c*, ought all to intersect in the point on the sketch denoting your position, therefore it is only necessary to resect the line A*x* from either B or C; but it will be better to do it from both, if only to prove the correctness of your work.

2. Take the points A, D, and C, and find your position either by the "three-point problem" as explained in last answer, or by the "method of adjustment," which is done as follows:—

Take a piece of paper as transparent as possible, lay it flat on the plane-table, and stick a pin through the paper into the table in such a way that lines drawn from the pin towards the points A, D, and C will all fall on the paper. Pivoting the ruler on the pin, draw lines from the pin in the directions of these three points in the country. Mark each line so that there is no mistake regarding the point on to which it was directed; also designate which surface of the paper is to be kept uppermost.

Place the transparent paper on the sketch, and shift it about until the three lines on it pass through *their corresponding points on the sketch.* Prick through the point where the lines intersect, and that mark will represent your position.

Note.—If the operation of finding the position by means of the method of adjustment is to be done at once by an experienced hand, it will not be necessary to mark the lines and the surface; but it is a wise precaution to do so with beginners, and it should always be done when the information is required for future reference or for manipulation by another man (*vide* question 14). If the lines are not marked, there are two positions, and possibly three, which will fulfil the required conditions even when the proper surface is kept uppermost; and if that surface is put downwards, there are two, and possibly three more.

The point B can be used as a check to the accuracy or the work.

The reason why the points A, D, C were chosen in preference to any other three of the four fixed points is explained in the latter part of the answer to question 5.

3. Through R and Q draw magnetic north and south lines parallel to the vertical margins of the map; then from these two points set off the back angles of the observed bearings, namely, 113° from R and 59° from Q. The point of intersection of the two lines will mark your position.

4. See answer to question 2, Group XX.

5. It is difficult to tell what the examiner means by "the most convenient method." If transparent paper is available, the "method of adjustment" would probably be the most convenient; but if not, then the "three-point problem" is the only way under most circumstances.

With regard to the selection of the points, it should be noted that both these methods fail to give the wished-for result when your position and the three points are all on the circumference of the same circle, a contingency most unlikely

to happen, but still one to be guarded against, because *the nearer the observer's position is to the circumference of a circle passing through the three points, the more inaccurate will be the result of his work.*

There are two ways of avoiding such a contingency :—

(1) Select the points widely divergent—for instance, one on your right, one on your left, and another to your front. It follows, then, that your position cannot possibly lie on or near the circumference of a circle passing through the other three points, and, moreover, the intersecting angle which fixes your position will be a good one.

(2) If this is not possible, then try to get the *centre point nearer to you than the other two.* Then it follows that the circumference of a circle containing the three points will lie away from you, and your position cannot possibly be on it.

Let B A C represent the three points in the country, and *b a c* be their representations on the sketch (*a* lying between *b* and *c*), and *p* the position on the sketch of the observer which it is desired to find.

The student should remember that the success of the problem depends on his finding a point *x* on the sketch which will fulfil these two conditions :—

(1) It should lie in the circumference of a circle passing through the points *b*, *c*, and *p*.

(2) It should be in the line *pa* or *pa* produced.

Now if the four points *b*, *a*, *c*, *p*, are in the circumference of a circle, it follows from the latter condition that *x* must coincide with *a* or *p*, and in either case the solution will fail. It is also clear that the longer the line *xa* is, the more accurate will be the solution.

6. This may be done by either the "method of adjustment" or the "three-point problem," both of which are explained in the foregoing answers.

7. Choose two of the three points, selecting the two which will give the best angle of intersection at your position; then proceed as described in answer to question 3 of this

group. The third point may be used as a check to the accuracy of your work.

1060 yards.

8. (The examiner is supposed to mean that the operator is provided with a *prismatic* compass, and that the variation is known.)

Draw through the two points on the Ordnance map lines parallel to the vertical sides of the map. These lines will represent *true* meridians.

Set off from the same points the *magnetic* meridians according to the variation of the compass used.

Take the bearings of the two points in the country, and plot the back bearings from the two points on the map. The point of intersection will represent the observer's position.

9. When provided with a prismatic compass, choose two distant points in the country the position of which you can identify on the map, and proceed as described in last answer.

If unprovided with any instruments, use the method of adjustment or the three-point problem.

10. Take three mountain-peaks, and use the method of adjustment or the three-point problem.

11. Let A be the point in the country which is fixed on your sketch at *a*.

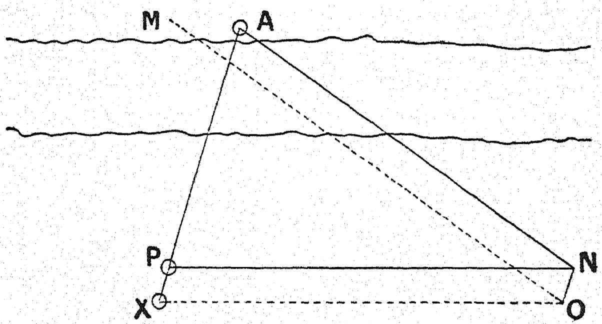
Take the bearing of A from the place you desire to commence your traverse, and from *a* plot the back bearing. In that line take any point X to represent your position.

Now take a bearing to some object O, not too far away, so as to get a good angle of intersection by the lines XO and AO. Plot the bearing from the point X. Pace to O and plot the distance.

Take the bearing of A from O and plot it. If when plotted the line passes through A, then you need go no

further, because X was the point you wished to find; but if the bearing does not pass through A, but to one side of it, as OM, then through A draw a line parallel to OM, and meet it with a line ON drawn through O parallel to AX. Through N draw a line parallel to OX, cutting AX in P.

P was your true position.



12. See answer to question 5.

13. Resection is the method of locating your position on a map by reference to the direction of other points in the country the positions of which are already fixed on the map and can be identified.

The essential difference between the operation of resection by the prismatic compass and by the plane-table lies in the fact that when working with the latter instrument the map must be set before the operation of resection is possible, whereas with the prismatic-compass sketch there is no such necessity. The reason for this is that, when working with the prismatic compass, the zero line is the magnetic meridian, which is quite independent of the sketch; whereas the zero line of a plane-table sketch is on the sketch itself, and therefore this line must be placed in a certain position with

reference to the country being delineated before any correct observations of direction can be made.

Resection by the "method of adjustment" is an exception to the above, because it is an independent set of observations, and can be applied equally well to a plane-table or a prismatic-compass sketch.

14. Both these reports are useless.

Lieut. E. should have stated either the true bearings of the three points or else have given the variation of the compass with which the observations were made.

Lieut. D. should have stated on the lines the points on which they were directed—thus, "to church," "to tower," "to cairn"—and then it would be plain which line was to pass through each point. Also the surface of the paper which should be kept uppermost should be stated.

15. First by the transparent paper, keeping the surface on which Plate XVI. is printed uppermost, and the junction of the three lines to the south of the three points. You will find the junction to be at X, but X is not visible from A, therefore it cannot be right. Now turn the other surface uppermost and try again. Y is now the junction, which is also invisible from A. Try again with the junction of the lines to the north. In one case we get V, which is not visible from C, and with the other surface uppermost we get W, which is visible from all three.

GROUP XXV.

SETTING MAPS.

1. Rule a line making an angle with the east or west margin of the map, equal to the magnetic variation of that particular compass.

Put the compass on this line so that the needle pivot is directly over the line, and turn the map with the compass on it until the position of the needle coincides with the line. The map is then set.

This proceeding would be rendered abortive if local attraction or atmospheric disturbances caused the needle to swerve from its normal position; also if the variation of the compass was not known the map would not be properly set.

2. This question must be considered with regard to two possibilities—

(1) When *a* can be identified on the map.

(2) When it cannot be identified.

When the position of *a* can be identified, place the table over that spot, align the ruler on the line *ac* on the map, and turn the table without moving the ruler until the sights are directed on C in the country. The table is now set, or "set up," as the examiner calls it.

When the position of *a* cannot be identified on the map, then set the map by working the "three-point problem." The map can thus be set without finding the position of *a*, or it can also be done by means of the "method of adjustment," which will enable the operator to determine the position of *a*, and then set the table as before.

3. It is scarcely likely that the examiner intended the examinee to exhaust in his answer all the possibilities contained in this question. He probably expected something

to be assumed which would admit of an answer of ordinary length.

The method chosen would depend on—

I. Whether the true meridian was marked on the map.

II. Whether or not the position of the observer can be recognised on the map.

III. How many points in the country round can be identified on the map.

IV. What instruments are at your disposal?

First, Let us assume that the true meridian is marked, and that you have a compass the variation of which is known (every officer should know the correct variation of his compass at the place in which he is serving).

Draw a line on the sketch making an angle with the true meridian equal to the amount of variation, and east or west of it, according to circumstances. Place the compass carefully on this line, so that the centre pivot is right over it; then turn the map with the compass on it until the needle and the magnetic N.S. line are in the same vertical plane. The map is now set.

Second, Let us assume that the true meridian is marked on the map, but we have not a compass.

We should now scan the country well to see if some prominent points therein cannot be identified on the map. If we are unsuccessful, then the map can still be roughly set, if the sun is shining, by the following method:—

Look at the time—say it is 10 A.M. (*i.e.*, two hours before noon). Set off a line making with the true meridian an angle of 30° (because the sun's apparent motion is 15° per hour), and to the *west* of it. Now hold up a plumb so that the shadow of the string falls across the map; turn the map, keeping the south end of the meridian towards the sun until the shadow coincides with the line you have drawn. The map, which should during this operation be kept horizontal, will now be roughly set.

Note.—Setting a map roughly in this manner is always a help to recognising points in the country round, and may therefore be considered as a preliminary to more accurate setting subsequently.

Third, Let us suppose that in this and subsequent cases no meridian is marked on the map.

In such a case it is necessary that points in the country, and more especially the observer's position, should be recognised on the map. When the observer's position and one more point can be recognised, proceed as follows :—

Lay a ruler joining these two points on the map, and turn the map without moving the ruler until its edge is directed on the distant point. Take care to keep the point representing your position towards yourself. The map is then set.

Fourth, Let us suppose that we were unable to identify the position on which we stand.

It will then be necessary to find three points in the country the positions of which can be identified on the map. We can then find our position by means of the "method of adjustment," and set the map as before, or else set it by the "three-point problem."

Fifth, Suppose, again, that our position cannot be identified, but we can leave it.

Identify on the map two points which you can recognise in the country. Go to one of these points and set the map by the other.

Sixth, If you were allowed to move, but still it was required to set the map at the position you now occupy.

Identify two points as before. Go to one of them, set the map by the other, and draw a line towards your original position. Now go to the other, set the map again by the first point, and draw another line towards your original position. The intersection of these two lines will show you the spot on which you wish to set the map, which can be done with reference to either of the other recognised points.

4. See last answer.

5. See answer to question 3 (second, third, fourth, fifth, and sixth cases).

6. In this question we have to do two things,—namely, set the map and fix our position on it.

First, Let us suppose we have a prismatic compass the variation of which is known.

Look about in the country round for two prominent points which can be identified on the map; through these two points draw magnetic meridians, take the bearings, and plot from each point its correct back-bearing. The intersection of these two lines will fix our position. The map may now be set by placing a ruler so that its edge touches our position and one of the distant points on the map: if the ruler be now aligned on the corresponding distant point in the country, the map is set.

Second, If no compass is available. It will be necessary in this case to recognise and identify on the map three points in the country. Your position can then be found by the method of adjustment, and the map set as before, or both can be done at once by the "three-point problem."

Third, If no compass is available, and only two points in the country can be identified on the map, it will be necessary to move from our position, and the method described in answer to question 3 (sixth case) will enable us to fix our original position and set the map.

7. Setting a map means placing it in its proper relative position to the ground it represents, so that every line on the map is either coincident with or parallel to the line it represents in the country.

(*a*) See answer to question 3 (first, second, and third cases).

(*b*) See answer to question 3 (fourth case).

GROUP XXVI.

VISIBILITY.

1. A is visible. B is visible. C is visible if the hill on which it is situated is flat on the top, and the contour which passes through C represents the crest, otherwise C is not visible. E is visible. F is visible. G is visible if the ground immediately to the right of G along the line GD is flat; but if that ground rises from G, then it is not visible. H is visible. K is not visible. M is visible.

2. 113 feet.

3. None of these points are visible from *b*, because from the formation of the ground it may be assumed that higher ground than *b* intervenes close to that point in the direction of F, C, and D. Even supposing the ground about *b* to be flat, these points would still be theoretically invisible, because they are all at a lower elevation than the point of observation, and the line of sight would pass over them.

4. D is not visible from C, because the knoll between these two points forms an obstruction. This is evident from an inspection of the map, since the line of sight falls from C to the top of the knoll about two contour intervals in a long distance, while from the knoll to D is a fall of about two contour intervals in a comparatively short distance. The gradient, therefore, is gentle at first and steeper afterwards, forming a convex section.

5. If we suppose the eye of the man standing at C to be 5 feet above the ground, he could possibly see the ground in the direction of B as far as the first contour; but after this the slope becomes steeper, and the ground would be invisible as far down as the river, and perhaps a little beyond, depending on the height of the river at the point

where the line of sight crosses it. If the river at this point is on or below level 90 feet, it would not be seen ; if on level 95 feet or higher, it would probably be visible.

From this point he can see the ground sloping up to the top of the knoll marked 135, but no more, because the gradient of depression from the top of the knoll to B is steeper than that from C to the knoll.

It is quite possible that a vedette at D would be invisible to a sentry at C, because the V.I. being a large one, there might be a knoll near D in the sentry's line of vision. This knoll, if its top was less than level 100 feet, would not have a contour round it, and consequently could not be shown on the map except by a form line.

6. Suppose the top of the map is north, a picquet could be marched from A along the road south-east in the direction of *b*, then along the unfenced road westwards towards B, and some distance down the fenced road in the same direction, before it became visible to the sentries in the village of B.

7. See Plate XIII. fig. 1.

The shaded parts are not visible from the church tower.

8. Between 306 and 310 feet above T.

9. Draw a line from the position of the sentry to the north-east corner of the wood—"Firs 30 feet high"—then along the eastern edge of the wood and straight south till you strike the road, then follow contour 950 eastwards until you meet the line from Y. The enclosed space is roughly all the ground the sentry could see, except a small patch near the top of the spur lying west of the above-mentioned wood.

10. At a point 990 yards beyond K on the line DK produced.

11. The ground between E and L is invisible for 1280 yards.

GROUP XXVII.

GRADIENTS ADMITTING OF MANŒUVRES.

1. Yes; I should say that at this place heavy waggons could not ascend without extra horses, but field-artillery might go up with ordinary teams, if the gradient continued for only a short distance.

2. 15°, but only with great difficulty.

3. Slopes up to 15°.

GROUP XXVIII.

RECONNAISSANCE OF ROADS, RIVERS, ETC.

1. Metalled or not, width of metalled portion, where metal or material for repairs can be got, present condition, whether level or hilly (stating steepest gradients), defiles, nature of fences, &c.

2. If strong enough to bear guns and heavy waggons, material (brick, stone, iron, or wood), breadth and length, number of arches and their span and form, height of roadway above water, thickness of piers, fords alongside. If the bridge is iron, state what kind of piers and abutments; also the girders, whether lattice, wrought, or cast iron, &c., &c.

3. See answer to question 1.

4. Breadth, depth, rapidity in miles per hour; nature of banks and bottom; command of one bank over the other, if any; fords, &c.

5. See answer to question 2.

6. Usually at 2 or 3 inches to one mile.

(*a*) See answer to question 1.

(*b*) Anything which may tend to retard the usual rate—such as steep gradients, broken places, rocky passes, deep mire, heavy sand, narrow defiles, &c., &c. The probable rate of march should be stated.

(*c*) Whether on or adjacent to the road, whether they command the road from the enemy's direction.

7. (*a*) See answer to question 1.

(*b*) 8 feet, but 9 feet is preferable.

(*c*) 8° for heavy waggons, except with extra horses.

15° for guns, but only for short distances.

8. *Buildings.*—Material, inflammable or not; defensibility, if commanded or not; materials for barricades or obstacles; whether suitable for barracks, hospitals, or magazines.

Bridges.—See answer to question 2.

Fords.—Breadth, depth, nature of bottom, rate of flow of water.

Soil.—Rough or smooth, marshy or dry, sticky clay or hard sand.

Rivers.—See answer to question 4.

Woods.—Whether they can be traversed or not, nature of undergrowth, nature of trees, extent, whether easily set on fire, any place for retrenchment, &c., &c.

Defiles.—Would they affect the rate of march or formation of the columns? are the sides accessible? best parts for defence; if it is a street, say whether it is paved or not, and nature of pavement; facilities for making obstacles or barricades, &c.

9. For *Bridges* and *Rivers* see answers to questions 2 and 4.

Railways.—Gauge, single or double line, stores and rolling stock available.

10. *Roadway.*—See answer to question 1.

Country.—Ground rough or smooth, marshy or dry, wooded or open; general nature of fences; character of cultivation; is the view restricted or not? is movement parallel to the roads possible? if so, for what arms? nature of woods, are they passable or impassable?

Halting-places.—Could the rear portion of the column pass to the front? could sentries get a good view of all approaches?

Camping-grounds.—Force capable of being accommodated, nature of soil, water-supply, sheltered or open situation, commanded or not, lateral approaches grassy or bare, &c., &c.

Ordinary camps.—

Infantry battalion	requires	120	yds. front	and	180	yds. depth.
Cavalry regiment	"	170	"	"	200	"
Cavalry squadron	"	70	"	"	80	"
Artillery battery	"	70	"	"	$161\frac{1}{2}$	"

Minimum camps.—

Infantry battalion	requires	60	yds. front	and	130	yds. depth.
Cavalry regiment	"	100	"	"	150	"
Artillery battery	"	70	"	"	$161\frac{1}{2}$	"

Lateral Communications.—Roads or tracks crossing or joining the road, their construction, width, and condition, &c., &c.

11. General nature of the valley; nature of stream, whether tidal or not; is it navigable? breadth and average depth, rate of flow, nature of bottom; banks high or low, marshy or hard; does one command the other? tributaries, islands, bridges, fords, boats, points favourable to passage, locks, facilities for making temporary bridges, &c., &c.

12. See answer to question 2.

13. (*a*) The position; (*b*) Advantages and disadvantages; (*c*) Country in the vicinity; (*d*) Communications; (*e*)

Bridges; (*f*) Rivers; (*g*) Woods; (*h*) Fences; (*i*) Obstructions; (*j*) Demolitions; (*k*) Trenches and other works.

14. General nature of the country through which the line runs; maximum gradients; gauge in feet and inches; single or double line; kind of rail, how fastened; transverse or longitudinal sleepers; spare rails and sleepers; description of bridges and state of repair, and best means of destroying them. Stations—size, defensibility, situation, whether on level, embankment, or cutting; length and breadth of platforms, could temporary ones be made? sidings, water for engines, drinking water, entrances and approaches to stations, room to form troops up outside, room and suitable sites for camps in the vicinity. Rolling stock, engines and their horse-power, carriages of each class, horse-boxes with their capacity, cattle and goods trucks, places other than stations where troops could be entrained. Telegraphs—number of wires, batteries, and instruments, stores of wire. Tunnels and cuttings and embankments, their length, facilities for defence or destruction. Junction lines, number and direction, do they lead to places from whence supplies can be drawn? &c., &c.

15. See answer to question 13.

16. See answer to question 2.

17. (*a*) *Bridges.*—See answer to question 2.

(*b*) *Towns and Villages.*—Material of which the houses are constructed; whether the houses are defensible or not, inflammable or not; whether the town is commanded by heights within artillery range; materials for making barricades and obstacles; can entrenching tools be got? are there any large buildings suitable for a keep or for barracks, stores, or magazines? nature of outskirts of village, &c., &c.

18. See answer to question 13.

19. See answer to question 1.

20. See answer to question 11, and add the following: Nature of approaches and points where access to the river may be barred by troops or obstacles; command of and distance from river of heights where artillery could be placed; places where inundations could be made; points suitable for covering the passage of troops.

21. See answer to question 10.

22. (*a*) See answer to question 4.

(*b*) Depth, rapidity, nature of bottom.
Infantry 3 to $3\frac{1}{2}$ feet.
Cavalry 4 to $4\frac{1}{2}$ feet.
Artillery $2\frac{1}{2}$ to $2\frac{3}{4}$ feet (with limber-boxes on limbers, &c.)

GROUP XXIX.

CONTENTS OF STACKS OF HAY AND STRAW, ETC.

1. $7\frac{1}{2}$ tons of hay and $5\frac{1}{4}$ tons of straw.

2. $11\frac{3}{7}$ tons of hay and 8 tons of straw.

3. About $17\frac{1}{5}$ tons of hay and 12 tons of straw.

4. About 3600 lb.

GROUP XXX.

SUPPLY OF WATER IN RUNNING STREAMS.

1. The formula $B \times D \times V$ (where B is the average breadth in feet, D average depth in feet, and V average velocity of the stream in feet per minute) will give the number of cubic feet of water flowing past a certain point in one minute.

Multiply by $6\frac{1}{4}$ to turn cubic feet into gallons, then multiply by 60 and 24 to turn minutes into days, and the result will be the number of gallons flowing past a certain point in one day.

As each man is allowed ten gallons a-day for all purposes, then $\frac{1}{10}$ of the number of gallons will give the number of men who can be supplied daily. Assuming in this instance that the average breadth of the stream is 4 feet and its average depth 3 inches, then—

$$4 \times \frac{1}{4} \times V \times 6\frac{1}{4} \times 60 \times 24 \times \frac{1}{10} = 15{,}000.$$

$$\therefore V = 16\frac{2}{3} \text{ feet per minute.}$$

Note.—It will be seen that the latter part of the above multiplication—viz., $6\frac{1}{4} \times 60 \times 24 \times \frac{1}{10}$—generally remains constant; and as these figures multiplied together equal 900, it will be sufficient in normal cases to use the formula—

$$B \times D \times V \times 900 = \text{number of men.}$$

2. 18,000.

3. 2 feet broad, 3 inches deep, and flowing at the rate of 40 feet a minute.

4. 20 feet a minute.

5. 28,125 men.

6. 8800 men.

GROUP XXXI.

CALCULATION OF HORIZONTAL ANGLES FROM GIVEN BEARINGS.

1. 65°.

If the right angle at C was required to the south of the line AC, I should set off a line from C bearing 175°; and if it was required to the north, the bearing would be 355°.

2. At A 65°, at B 90°, at C 25°.

3. At A 70°, at B 110°, at C 70°, at D 110°.

4. At A 45°, at B 45°, at C 90°.
B is 800 yards from C and 1131 yards from A.

5. At W 97°, at X 75°, at Y 122°, at Z 66°.

GROUP XXXII.

EXERCISES IN THE USE OF THE MARQUOIS SCALES.

1.

(*a*)	30 on the	30 scale.		(*j*)	20 on the	30 scale.	
(*b*)	15 "	30	"	(*k*)	25 "	35	"
(*c*)	10 "	40	"	(*l*)	6 "	50	"
(*d*)	10 "	60	"	(*m*)	6 "	30	"
(*e*)	5 "	40	"	(*n*)	3 "	20	"
(*f*)	5 "	45	"	(*o*)	21 "	30	"
(*g*)	5 "	60	"	(*p*)	42 "	30	"
(*h*)	$2\frac{1}{2}$ "	40	"	(*q*)	2 "	50	"
(*i*)	1 "	40	"	(*r*)	50 "	40	"

2.

(*a*)	3	on the	30	scale represents	1 foot.
(*b*)	5	"	60	"	1 "
(*c*)	3	"	25	"	1 "
(*d*)	3	"	20	"	1 "
(*e*)	7	"	25	"	1 "
(*f*)	4	"	35	"	1 "
(*g*)	4	"	30	"	1 "
(*h*)	8	"	25	"	3 feet.
(*i*)	12	"	25	"	1 foot.
(*j*)	3	"	25	"	1 "
(*k*)	5	"	30	"	1 "
(*l*)	4	"	25	"	1 "
(*m*)	5	"	45	"	1 "
(*n*)	3	"	20	"	1 "
(*o*)	4	"	35	"	1 "
(*p*)	4	"	90	"	1 "
(*q*)	3	"	50	"	10 feet.

3.

(*a*)	5	on the	40	scale represents	1 yard.
(*b*)	1	"	20	"	1 "
(*c*)	1	"	60	"	1 "
(*d*)	4	"	30	"	10 yards.
(*e*)	1	"	40	"	2 "
(*f*)	1	"	35	"	5 "
(*g*)	1	"	45	"	1 yard.
(*h*)	1	"	60	"	10 yards.
(*i*)	3	"	35	"	20 "
(*j*)	1	"	50	"	5 "
(*k*)	9	"	25	"	100 "
(*l*)	3	"	50	"	20 "
(*m*)	1	"	30	"	1 yard.
(*n*)	1	"	40	"	2 yards.
(*o*)	4	"	25	"	1 yard.
(*p*)	1	"	50	"	3 yards.
(*q*)	1	"	25	"	7 yards.
(*r*)	1	"	20	"	10 yards.
(*s*)	3	"	20	"	40 "
(*t*)	3	"	50	"	10 "
(*u*)	1	"	40	"	20 "

GROUP XXXIII.

ACCOMMODATION FOR MEN AND HORSES.

1. If the inhabitants are to be turned out altogether, about 2280 men could be accommodated; but if they are to remain, about one-half that number.

2. 42 men.

3. 16 horses.

GROUP XXXIV.

MISCELLANEOUS EXAMPLES.

1. (*a*) By bearing and measurement, or back-bearing and measurement.

Take a bearing to the object, plot that bearing, measure the distance, and lay off according to scale.

If you are standing *at* the object, then take a bearing to some conveniently situated object the position of which is marked on your sketch, plot the back-bearing, and measure as before.

(*b*) By intersection.

From a point in the country the position of which is fixed on your sketch, take a bearing to the object and plot that bearing; then go to some other point which is also fixed on the sketch and do the same: the intersection of these two lines will fix the position of the object.

N.B.—The two points should be chosen so that the intersecting angle shall neither be too acute nor too obtuse.

(*c*) By resection.

Being at the point the position of which you want to fix, take the bearings of two other points in the country, the

positions of which are fixed on the sketch. Plot from each point the back-bearings, and the intersection will fix the required point.

(*d*) By reference to one inaccessible point.

This method is fully described in answer to question 11 of Group XXIV.

2. Reference points are points on a sketch the relative heights of which have been found and registered for future use. For instance, suppose the surveyor is standing on contour 200 feet, facing a valley: with his clinometer reading zero, he looks along the slopes opposite him and notes if there are any points fixed on his sketch which are on the same level as his present position. If he continues to do this at different levels, he will fix the altitudes of a number of points which will be of great use to him, because he can whenever he likes at any future time find his proper relative level by reference to one of these points.

Let us suppose, for example, that a surveyor wishes to begin contouring at a certain point (the altitude of which he does not know), after he has put in the contours in a distant part of the sketch. He cannot start until he determines the proper relative level of the place on which he stands. He looks about until he sees one of his *reference points*, and to that he takes an angle of elevation or depression, as the case may be; he then measures the distance by scale, and calculates his level by the usual formula.

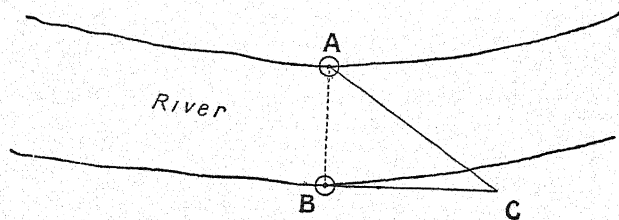
3. Take the map to some commanding situation which you can identify on it, and set it by the country. Now look on the map for the representations of certain conspicuous points which you can see in the country round. Align the ruler on your position and each of these points in succession, and ascertain if the ruler is correctly pointed in each case to the corresponding objects in the country. This will show if the map is correct with regard to the *positions* of the main features.

Now take the clinometer and observe the angles of eleva-

tion or depression to different objects around. Calculate their heights, and compare with the map. You will thus test the general correctness of the contouring.

In order to test the details and to see if the map is up to date, take a straight line across country and pace along it. See if the roads, streams, and other details come in their proper places and are all marked.

4. The simplest way is to take a point A on the opposite bank, and, standing at B on your bank, take a bearing to A —say it reads 47°. Now take the direction of a line BC at



right angles to BA, which in this case should bear 137°. Move along the line BC until the bearing of A is 2°. You then know that the angle BCA is 45°, and AB will be equal in length to BC.

5. The successive operations in making a deliberate military sketch are as follows :—

(*a*) Selection of base and intersection of stations.
(*b*) Traversing.
(*c*) Contouring.

(*a*) This has for its object the accurate fixing on the sketch the positions of certain conspicuous points in the country round.

(*b*) This is used for filling in the details. It consists in observing and laying down on the sketch the directions and lengths of a series of straight lines along roads or across

country, and fixing the positions of other objects with reference to these lines.

(c) This consists in measuring slopes, calculating heights, and showing these, as well as the shapes of the features, by means of contours at a certain vertical distance apart.

6. See answers to questions 4 and 8, Group XI.

7.

Slow,	1 mile per hour.	
Ordinary,	2 miles	"
Rapid,	3 "	"
Very rapid,	5 "	"
A torrent,	6 "	"

8. I would go to a point in the country which I could accurately identify on the map, and take a bearing to some other point which I could also identify. Having joined these two points, I would lay off from the one representing my position the direction of magnetic north in accordance with the bearing observed; then, knowing the variation of my compass, I could lay off the direction of true north.

Say that you elect to stand at the point C on the ground represented in diagram IX., and that you take a bearing to the centre of the knoll situated between C and D. Suppose this bearing reads 30°. Now from C lay off a line towards the top of the map making an angle of 30° with the line joining C to the knoll; this line is evidently the direction of magnetic north. Suppose that the variation of my compass is 17° west, I will now lay off another line from C making an angle of 17° with the magnetic north and to the east of it. This line will show the direction of true north.

9. (a) Find two points in the country which can be identified on the map. Measure the distance between these two points on the map and also on the ground. Then paper length in inches divided by ground length in inches gives the R.F. of the map

(b) Look for two points on contours if possible, and recog-

nise these two points on the ground. Go to one of them and find the angle of elevation or depression to the other; measure the distance on the ground, and ascertain by calculation the difference in level between them; divide this by the number of contour intervals between the two points on the map, and the quotient will give the V.I.

N.B.—If it is stated that the contours are normal, the above operation will of course be unnecessary.

(*c*) The north points can be determined as described in last answer.

10. See last answer.

11. Working down-hill, because it is less fatiguing and more can be seen.

12. See answer to question 3.

13. See answer to question 8, Group XXI.

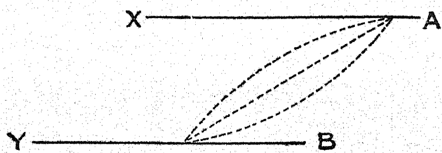
14. (1) Contours serve to show—1st, The relative altitudes of the different objects on the sketch; 2nd, the slopes of the ground at all parts; 3rd, the general shape and formation of all the features.

(2) See answer to question 17, Group VII.

15. See answer to question 9.

16. Proceed to some commanding point which can be identified on the map, and on a contour if possible. If not on a contour, the height of this point must be accurately found. Now make observations with the clinometer down the slopes all round you. Whenever the ground slopes uniformly, the spaces between the contours on the map may be divided into ten equal parts, but this will not always be the case, because on account of the large V.I. the positions of many of the knolls or other eminences and undulations of considerable height will be unmarked unless a contour line happened to cut them individually

The positions of such places should be found by intersection or resection, and their heights found by calculation. It will then be an easy matter to carry the interpolated contours round them.



Also with such a large V.I. the slopes of the ground are not accurately shown, for suppose the lines XA and YB represent contours at 100 feet V.I., the slope of the ground from A to B may be as shown by either of the dotted lines —*i.e.*, it may be either convex, uniform, or concave. In the first instance, the interpolated contours must be spread out at the top and closer together at the bottom of the slope, and *vice versâ* if the slope is concave.

It will much facilitate work if the sketcher would make a scale of horizontal equivalents for 10 feet V.I. on a scale of 6 inches to one mile, on the edge of a piece of paper or a card preparatory to commencing.

303¾°

17. ~~384¾°~~, 247½°, 78¾°, 213¾°, 146¼°, 112½°.

18. 17 knots.

19. The contours would occur at 7·2 miles apart on the ground, or 72 inches apart on paper.

20. 25° west is the variation when the point is west of meridian.
35° west is the variation when the point is east of meridian.

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ard Time meridian and that of the place of observation, depending upon whether the latter is east or west of the former.

Thus, if by the watch the Standard Time is 8 A. M., then the local mean time of a place 5° east of the Standard Time meridian will be 8:20 A. M., and of a place 5° west, it will be 7:40 A. M.

Local time. When local mean time is carried by a watch or chronometer it is the one most conveniently used in making observations on the sun out of the meridian, data for which is obtained from page II. of each month in the Nautical Almanac. But for making observations on the sun when on the meridian, as in making the adjustments of solar attachments, and determining time and latitude, local apparent time should be used, data for which is given on page I. of each month in the Nautical Almanac.

Arcs of great circles are reckoned in degrees, minutes, and seconds *of arc*, and also in hours, minutes, and seconds *of time;* thus 24 hours is equal to 360°, 1 hour is equal to 15°, 1 minute is equal to 15′, and 1 second is equal to 15″.

In civil reckoning of time the day begins at midnight, and hours are counted up to 12 at midday, and again up to 12 at the following midnight.

In astronomical reckoning the day begins at midday (12 hours after the civil day), and hours are counted up to 24, to the following midday. January 1st, astronomical time, is the afternoon of January 1st, civil time, and forenoon of January 2d, civil time.

Observations for time consist in observing the transit of the sun, or a star, across the meridian, noting the watch time and finding the difference between it and the calculated local mean or sidereal time of transit; the difference being the error of the watch.

The time of transit of the sun is obtained by taking the mean of the times of transit of the east and the west limbs.

When making use of stars it is usual to observe two (not circumpolar, as their apparent motion is too slow), so as to eliminate instrumental errors. From the Nautical Almanac, as explained therein, is obtained the mean time of transit of each of the two stars. The telescope is placed in the meridian (both motions in azimuth clamped) and then turned up to the *first* star and the exact time of its transit noted. The telescope is then plunged and the alidade revolved 180°, the telescope again placed in the meridian, raised to the altitude of the *second* star, and the exact time of its transit noted.

The mean of the errors of the watch is the error to obtain correct time.

For stars having high altitudes, the eye prism would have to be used.

The meridian may be established either by two points in it, one of which is occupied by the instrument and the other by the target, or by the azimuth of some other station.

LONGITUDE.—*By chronometers.* Finding the difference in longitude between two places is a more complicated problem than finding the latitude of a place. If it were possible to construct a timepiece to show *mean* or *sidereal* time without any variation, all that would be necessary would be to set it at the exact time at the initial station, carry it to the station whose longitude was desired, and there make an observation for time; then the error of the timepiece at the instant of the observation would be the difference in time, or the difference in longitude in time, which could be converted into difference in longitude in degrees, minutes, and seconds, but such perfection has not been obtained, and the rate of variation from mean or sidereal time has to be obtained and applied. Thus the error of timepiece (called chronometer) is noted on the *mean* or *sidereal* time on a fixed meridian on a given date. Assuming it to preserve a constant rate, it is carried to the place whose longitude is desired, an observation made for time, and

the error at that instant is compared with the calculated error at the same instant at the meridian of departure. Navigators at sea depend chiefly upon this method, and it may be used for short distances on land, but cannot be depended upon for great differences.

By telegraph. The method now exclusively employed in geodetic operations, where possible, is to make a most accurate determination of time at both places to be compared, combined with a direct comparison of these times through the medium of the electric telegraph. The most simple one is for each observer to regulate his chronometer to local mean or sidereal time, and to note the time of any arbitrary break of the connecting circuit, by some prearranged signal.

Or, to telegraph from an eastern to a western station the instant of a fixed star's culmination at the eastern station, and conversely to telegraph to an eastern station the instant of culmination of the same star at a western station. The local time of both events being noted, the difference, as recorded at the same station, corrected for the rate of the timepiece, gives the difference of longitude.

Many improvements and refinements of this method are used for accurate determination.

Longitude by eclipses of Jupiter's satellites. At one time the eclipses of Jupiter's satellites were much used in determining longitude, but, since a satellite never enters the planet's shadow suddenly, because of its sensible diameter, the time from its first loss of light to its total extinction is quite perceptible. The same is true of emergence. Owing, also, to the difference in telescopes and eyes, this becomes a source of discrepancy in the times assigned by different observers for the beginning and ending of an eclipse. If, however, both be observed by the same person and with the same telescope, the half sum of the two times, as given by a properly regulated timepiece, will be that of apparent opposition, measurably free from error.

In the Nautical Almanac is given the mean time at Washington of the conjunctions of the satellites of Jupiter. If, then, the local mean time be noted of one of these on any particular day at a place whose longitude is desired, the Washington mean time at the same instant may be approximately obtained, and hence the difference of longitude.

THE SUN'S DECLINATION.—The sun apparently revolves about the earth once a year in the celestial ecliptic; and as the plane of the ecliptic makes an angle of 23° 28′ with the plane of the equator, the sun during the six months of the year from March 20th to September 22d is above the equator and its declination is north, reaching its maximum of 23° 28′ June 21st; and from September 22d to March 20th it is below and its declination south, reaching its maximum of 23° 28′ December 21st. On March 20th and September 22d, when crossing the equator, its declination is zero. The change in declination, however, is not constant, being as much as 59″.25 per hour when crossing the equator, and less than 1″ per hour when at its maximum points; therefore, when going to use a solar attachment, it is necessary to prepare beforehand a table of hourly declinations of the sun for each day.

Determining the declination. When the sun is on the meridian of Greenwich, England, at *apparent noon* of any day he will have a certain declination, which is given in the Nautical Almanac page I. of each month. At a place 15° west longitude from Greenwich it will be only 11 o'clock A. M. *apparent time*, but his declination for that hour will be the same as at Greenwich apparent noon. Now when the sun arrives at the 15° meridian, one hour of time will have passed and his declination will also have changed, which hourly change is also given in the Nautical Almanac. At a place 90° west longitude from Greenwich it will be only 6 o'clock A. M. *apparent time* when it is apparent noon at Greenwich, but the instant is the same as regards the declination of the sun, as

given in the Nautical Almanac, and similarly for any other place whose longitude is known.

At Greenwich *mean noon* the sun has a certain declination each day, given on page II. of each month of the Nautical Almanac. At a place 15° west longitude it will have the same declination at 11 A. M. *mean time*, and at 90° west longitude the same at 6 A. M. *mean time*. To determine the declination for any other time of day the hourly change is applied as will be explained.

As the Nautical Almanac gives the declination of the sun in the heavens *unaffected by refraction*, it becomes necessary to *apply such an amount of refraction* to those declinations as will bring them up to the apparent heights before they are to be set off on the declination arc.

As before stated, before this instrument can be used at any given place it is necessary to set off, on the declination arc, the declination of the sun as affected by its refraction for the given day and hour, and, on the vertical circle, the co-latitude of the place where the observation is made.

The declination of the sun, given in the Nautical Almanac from year to year, is calculated for both *apparent* and *mean noon* at Greenwich, England, together with its hourly change in declination. To determine it for any other hour at the same or any other place, a correction must be applied for the change in declination due to change in time, from hour to hour, and also for the difference in time due to the difference in longitude.

The longitude of any place in the United States can be found very nearly by reference to a good map, or it is the general practice now, where standard railway time is carried and is known not to differ more than half an hour from local time, to use that, and make the corrections in declinations corresponding to it. Having thus the difference in time, the declination for a certain hour in the morning, which would be

earlier or later as the longitude was greater or less, would be the same as that of Greenwich mean noon on the given day. Thus, supposing the observation be made at a place, say 5 hours earlier than at Greenwich, then the *declination* given in the almanac for the given day at mean noon, *corrected for refraction*, would be the apparent declination at the place of observation at 7 o'clock A. M.; this gives a starting-point.

To obtain the apparent declinations for the other hours of the day, take from the Almanac the declination for mean noon of the given day, and, as the declination is increasing or decreasing, add to or subtract from the declination of the first hour the difference for one hour, as given in the Almanac, which will give, when affected by the refraction, the apparent declination for the succeeding hour; proceed thus in making a table of the apparent declinations for every hour of the day. For example, suppose it were required to make out a table of declinations, corrected for refraction, for the different hours of May 1, 1893, at Fort Leavenworth, Kansas, in longitude 94° 51′ 7″ or 6 hours 19 minutes 24 seconds, and latitude 39° 21′ 24″.

Calling the longitude 6 hours 20 minutes, then the declination given in the Almanac for mean noon of May 1, 1893, at Greenwich, will be the declination at supposed place of observation at 5:40 A. M. of same day, and is N. 15° 13′ 54″.9; the change for one hour is +45″.04; the plus sign indicates that north declinations are increasing. Since 7 A. M. is about as early as the attachment can be reliably used, the sun by that time will have been changing his declination for 1 hour 20 minutes, or $1\frac{1}{3}$ times 45″.04=60″.05, which added to his declination at 5:40 A. M. gives N. 15° 14′ 54″.95 for his declination at 7 A. M. To find the declinations for the remaining hours of the day and corresponding refractions, proceed as follows: Calling the latitude 40°, refer to the table of mean refractions and find the hourly amounts to be applied. 7 A. M. being the 5th hour.

Dec. at 7 A. M. N.	15° 14′ 54″.95	+ Ref. 5h 1′ 31″	= 15° 16′ 25″.95	= App. Dec. 7 A. M.
Add. Diff. for 1h.	45″.04			
8 A. M.	15° 15′ 39″.99	+ Ref. 4h 55″	= 15° 16′ 34″.99	= App. Dec. 8 A. M.
	45″.04			
	15° 16′ 25″.03	+ Ref. 3h 40″	= 15° 17′ 5″.03	= App. Dec. 9 A. M.
	45″.04			
	15° 17′ 10″.07	+ Ref. 2h 32″	= 15° 17′ 42″.07	= App. Dec. 10 A. M.
	45″.04			
	15° 17′ 55″.11	+ Ref. 1h 27″	= 15° 18′ 22″.11	= App. Dec. 11 A. M.
	45″.04			
	15° 18′ 40″.15	+ Ref. 0h 27″	= 15° 19′ 7″.15	= App. Dec. 12 M.
	45″.04			
	15° 19′ 25″.19	+ Ref. 1h 27″	= 15° 19′ 52″.19	= App. Dec. 1 P. M.
	45″.04			
	15° 20′ 10″.23	+ Ref. 2h 32″	= 15° 20′ 42″.23	= App. Dec. 2 P. M.
	45″.04			
	15° 20′ 55″.27	+ Ref. 3h 40″	= 15° 21′ 35″.27	= App. Dec. 3 P. M.
	45″.04			
	15° 21′ 40″.31	+ Ref. 4h 55″	= 15° 22′ 35″.31	= App. Dec. 4 P. M.
	45″.04			
	15° 22′ 25″.35	+ Ref. 5h 1′ 31″	= 15° 23′ 56″.35	= App. Dec. 5 P. M.

At apparent noon, May 1, 1893, it will only be 11 hours 56 minutes 56.09 seconds mean time, hence the sun on the meridian will have the declination corresponding to that mean time instead of 12 M. mean time, as given in the table. What the exact declination for apparent noon is may be found from page I., or by subtracting from that given in the table the amount of change for 3 minutes 3.91 seconds (the difference between the times) which equals 2″.3 in declination giving a declination at apparent noon of 15° 19′ 4″.85.

From March 20th to June 21st add hourly differences in declination; from June 21st to September 22d subtract hourly differences; from September 22d to December 21st add hourly differences; from December 21st to March 20th subtract hourly differences.*

*If the observer's watch shows the standard time of Saint Louis (90th meridian) and the first method of determining the meridian is used, the table of declinations is computed for Saint Louis, not for the observer's longitude. When the observer's watch shows 9 A. M., it is 9 A. M. mean time at Saint Louis, not at the observer's position.

TO DETERMINE THE LATITUDE OF A PLACE.—In the explanation of the Table of Refractions it was stated that the refractions were calculated for latitudes at intervals of 2½ degrees, which is as near as required for finding the apparent declination to set off on the declination arc, but to use the instrument for determining the meridian it is necessary that the latitude of the place should be known accurately, in order to set off the co-latitude. If this is not known, it may generally be found from a map within the 2½ degrees for determining the apparent declination to set off in preparing the tables. Having done this, set off on the declination arc the apparent declination for 12 o'clock apparent noon of the given day. A few minutes before apparent noon set up the instrument and level carefully; set the declination arm at 12 o'clock on the hour ring and revolve the alidade in azimuth until the declination arm points towards the sun (Fig. 170). Set off the co-latitude approximately on the vertical circle, and clamp; then by means of the tangent screw bring the sun's image between the equatorial lines. As the sun continues to rise towards the meridian his image will descend; follow it with the tangent screw, keeping it between the equatorial lines, and by either lower tangent screw keep his image between the hour lines. On reaching the meridian his image will cease to descend and begin to rise. When this instant occurs, cease to follow it, and read the vertical circle, which will be the co-latitude of the place. The co-latitude thus found may be used with the instrument without regard to whether the vertical circle has an index error or not; but if the true co-latitude is used with it, any index error must be determined and properly applied in setting it off, as also in determining the true co-latitude by a meridian observation, as above.

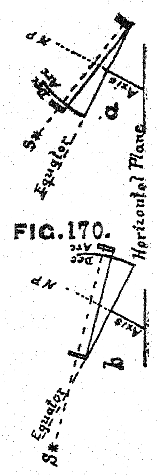

FIG. 170.

By observations on circumpolar stars. The latitude of a place being equal to the altitude of the pole, measured at the

place, the operation consists in simply observing the altitude of a circumpolar star at culmination, and correcting this altitude for refraction and for the pole distance of the star.

From a *table of culminations* find the time Polaris, or some other circumpolar star, crosses the meridian. About 15 or 20 minutes before this time set up the transit and level carefully. Set the horizontal wire of the telescope upon the star and follow it with the tangent screws until it reaches its highest or lowest point. Read the vertical angle and from it subtract the refraction corresponding to the reading, and then subtract if upper culmination, or add if lower culmination, the polar distance, and the result should be the latitude of the place.

Errors of adjustment of line of collimation, of vertical circle, and of plate bubbles may be eliminated by determining the altitude of the star with the telescope direct about 5 minutes before culmination, then plunging the telescope and revolving alidade 180°, releveling, and again determining altitude, telescope reversed, by two readings. Then plunge telescope back to normal position, revolve alidade 180°, again relevel, and make another determination, telescope direct. Correct the mean of the four readings for refraction and pole distance as before.*

If the vertical arc of the transit is only 180°, an artificial horizon, as used with the sextant, may be employed, and an observation made, first to the star direct, and then to its image in the artificial horizon. The sum of the two observations will be double the apparent altitude of the star. Or, the first observation may be taken on the star direct, then two on its image in the artificial horizon, then another on the star direct, their sum giving four times the apparent altitude of the star, from which its altitude, and then the altitude of the pole or the latitude, may be obtained. The error due to an index error of the vertical circle will thus be eliminated.

*Errors of adjustment of the plate-bubble perpendicular to the ine of sight and of the standards are not eliminated.

By meridian altitude of the sun, without solar attachment. The latitude of a place is equal to 90° — the meridian altitude of the sun + his declination (provided north declinations be considered positive and south negative). Or, when the observer and sun are upon the same side of the equator, the latitude = 90° — the meridian altitude or the sun + the declination. When the observer and the sun are upon different sides of the equator, the latitude = 90° — the meridian altitude of the sun — the declination.

Hence, *to find the latitude by an observation on the sun*, make an observation for the altitude of his upper or lower limb when on the meridian at apparent noon, subtract meridian refraction, subtract his semi-diameter if on upper, or add if on lower limb, for the true altitude of the center, which latter subtract from 90°, and add the declination with its proper sign.

TO DETERMINE THE MERIDIAN WITH SOLAR ATTACHMENT.—Having now all the necessary data for using the instrument, to determine the meridian, or true north-and-south line, at any time of the day, take from the table the apparent declination corresponding to the mean time when the observation will be made, and set it off on the declination arc; set off on the vertical circle the co-latitude of the place, clamp the horizontal plates at zero, revolve the whole head of the instrument until the telescope is *approximately* in the meridian, then with one hand turn the declination arm on the polar axis toward the sun, and with the other turn the whole head of the instrument until the image of the sun is brought between the equatorial and the hour lines; then clamp the head, and by means of lower tangent screw and movement about polar axis keep the image there until the exact instant for which the declination is computed, when the telescope will be in the meridian.*

*Or another method is to set the hour circle at the hour for which the declination is computed, and clamp; set off the declination and co-latitude as before, and about ten minutes before the computed time bring the sun on the plate between the equatorial lines and keep it

When the instrument is accurately adjusted and leveled, and the corrected declination of the sun for the day and hour and the co-latitude of the place are set off on their respective arcs, the image of the sun cannot, at the given hour, be brought between the equatorial lines until the polar axis is placed in the plane of the meridian of the place, or in a position parallel to the axis of the earth, and the line of collimation of transit telescope is in the meridian. (See foot-note, p. 220.)

The slightest deviation from this position will cause the image to pass above or below the lines. Thus from the position of the sun in the heavens is obtained the true merdian with an accuracy corresponding to the accuracy of the adjustments and observation.

If the revolving arm be turned a little to one side of its proper position, a *false* image may appear in nearly the same position as that occupied by the true one. It is caused by the reflection of the true image from the surface of the arm. It can be distinguished by being much less bright and less clearly defined.

SMITH'S MERIDIAN ATTACHMENT.—*Description.* This attachment, shown in the figure and used in connection with the transit, consists of a small solar telescope free to revolve in the collars K, K. The collars are rigidly attached to the transit telescope, and therefore the only motion independent of the transit telescope possessed by the solar telescope is that of revolution about its longitudinal axis.

The amount of this revolution is recorded on the hour circle by an index on the upper collar K, the hour circle being a silvered ring graduated to ten minutes of time and rigidly attached to the solar telescope just above this upper collar.

The vertical limb of the transit is used as a latitude arc.

The declination arm is shown in the figure. Attached to the pivot end of this arm, and moving with it, is the re-

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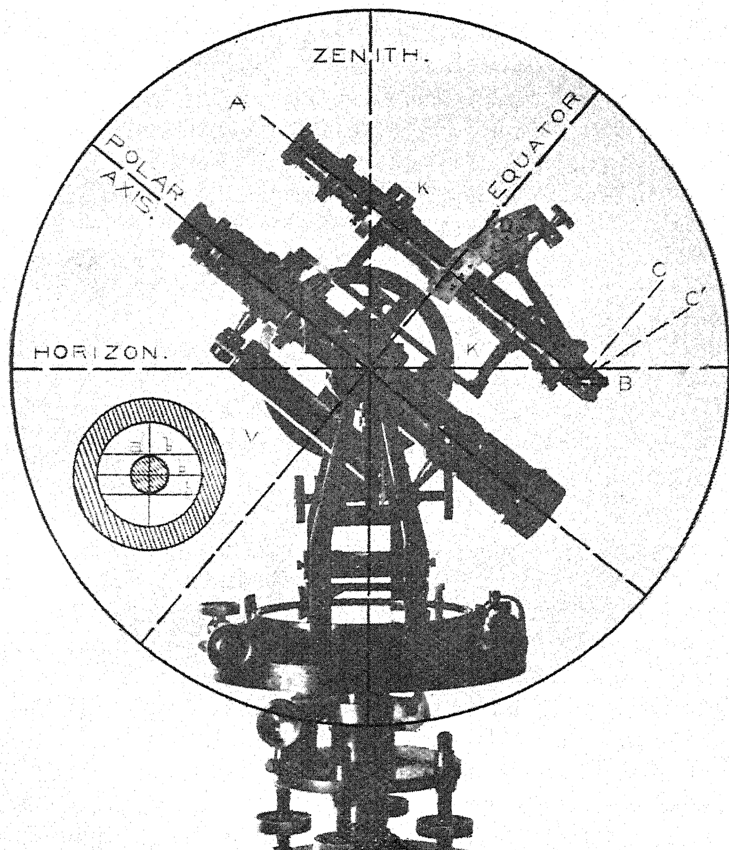
between them by moving the head of the instrument in azimuth by the lower tangent screw until the image appears between both the hour and equatorial lines—at this instant the telescope is in the meridian.



SMITH'S MERIDIAN ATTACHMENT.—B, reflector; K, K, collars; V, vertical limb, latitude arc; D, declination arc; A, B, C, C', solar line of collimation; a, hour wire; b, b, b, equatorial wires. The line A B is parallel to the polar axis; and, as regards latitude, declination, and hour angle, is practically identical with it.

flector, so arranged that when the declination vernier, properly adjusted, reads zero, the angle between the reflector and the optical axis of the telescope is 45°.

THEORY.—If the instrument, properly adjusted, be set in the meridian, and the latitude of the place set off on the latitude arc, the polar axis of the instrument will be parallel to the earth's polar axis.

If the declination vernier be set at zero, the portion of

the line of collimation of the solar telescope from the reflector outward will make an angle of 90° with the optical axis of the solar telescope. And if the solar telescope be now revolved in its collars, this outward portion of the line of collimation will cut from the celestial sphere a circle parallel to and (on account of the infinite radius of the celestial sphere) coincident with the celestial equator.

If the apparent sun is on the equator at the time the solar telescope is being revolved, it will, when the telescope has been turned through the proper angle, be in the outward portion of the line of collimation, and its image will appear accurately on the cross-wires.

So, too, with the instrument as before, if the sun's declination for a particular day and hour, corrected for refraction, be set off on the declination arc and the solar telescope revolved, this outward portion of its line of collimation will cut from the celestial sphere a circle parallel to the equator and at a distance from it equal to the sun's declination for the selected time, corrected for refraction. When, therefore, the solar telescope has been revolved through the proper angle, its line of collimation will strike the sun and the image of the latter will appear accurately on the cross-wires.

If, however, the polar axis is not parallel to the earth's axis (when the instrument is properly adjusted and set up and the latitude set off on the latitude arc, this lack of parallelism occurs whenever the instrument is not in the meridian), the outward portion of the line of collimation no longer cuts from the celestial sphere the circles described, and the sun's image cannot be brought upon the cross-wires.*

It therefore follows that, when the conditions mentioned regarding adjustment, setting up, latitude, and declination *are*

* There is one exception to this rule. The image *can* be brought upon the cross-wires when the telescope is no longer in the meridian; but in this position the transit telescope will point on the side of the sun opposite the meridian, and on the hour circle A. M. time will be used for P. M. observations, and the converse.

fulfilled, the instrument is in the meridian when the sun's image is brought accurately upon the cross-wires.

ADJUSTMENTS.—Before adjusting the attachment, see that the transit itself is in the most accurate adjustment possible.

To adjust the equatorial wires. Set up the instrument, and by the most convenient means bring the sun's image between the equatorial wires. Revolve the solar telescope slightly in its collars, so as to cause the image to traverse the field of view. If the image remains between the wires while traversing the field, the adjustment is correct.

If it does *not* so remain, loosen the screws holding the cross-wires diaphragm in place, and with the hand revolve the diaphragm until the image *will* remain accurately between the equatorial wires while traversing the field of view.

Errors from lack of this adjustment can be avoided by always centering the image on the hour wire as well as between the equatorial wires when making an observation.

To adjust the line of collimation of the solar telescope. Remove the two screws that fasten the base of the reflector frame to the solar telescope, and push the reflector to one side. Set the line of collimation of the transit telescope on some distant point, preferably a star (in which case the cross-wires must be illumined), and bring the line of collimation of the solar telescope upon the same point by means of the capstan screws carrying its diaphragm.

If no distant point is available, two points, the second above the first as far as the axis of the solar telescope is above that of the transit telescope, may be used.

To adjust the declination arc. Set up the instrument in the meridian, set off the latitude, and make a meridional observation of the sun, bringing its image accurately between the equatorial wires by means of the tangent screw on the declination arm. The difference between the reading of the declination vernier in this position and the corrected declination of the sun for the time of observation will be the index error of the arc.

Loosen the three small screws holding the arc in place, and remove this index error by shifting the arc until its vernier reads the corrected declination. Tighten the screws, being careful not to shift the arc from its corrected position.

If the arc is not adjustable, the index error must be applied each time the declination is set off.

To adjust the hour circle. Set up the instrument in the meridian, set off the latitude and the corrected declination. Then make an observation of the sun; being careful to center the image on the hour wire. If the index reads the local apparent time of the observation, the adjustment is correct. If not, mark a new index opposite the correct local apparent time of the observation.

TEST FOR ACCURACY.—Whenever the solar attachment is to be used, it should be tested by the method required of deputy surveyors by the manual of surveying instructions issued by the Commissioner of the General Land Office. A complete description of the test is entered in the deputy's notes of survey.*

*"August 28, 1890: In order to test the solar apparatus, by comparing the results of observations on the sun, made during A. M. and P. M. hours, with a *true meridian*, determined by observations on Polaris, I proceed as follows:

"At 4 hours 2 minutes P. M. local mean time, I set off 45° 34′ 5 on the latitude arc; 9° 30′.5 N. on the declination arc; and mark the *true meridian* thus determined by the solar, by a cross on a stone firmly set in the ground, 5 chains north of the instrument.

"At 8 hours 56 minutes P. M. by my watch, which is 2 minutes fast of local mean time, I observe Polaris at *eastern elongation*, in accordance with instructions in the Manual, and mark the line thus determined, by a tack driven in a wooden plug set in the ground, 5 chains north of my station.

"August 29: At 6 A. M. I lay off the azimuth of Polaris, 1° 49′.5 to the *west*, and mark the TRUE MERIDIAN thus determined, by cutting a small groove in the stone set last evening, on which the true meridian falls 0.2 inch *west* of the mark determined by the solar.

"At 8 hours A. M., I set off 45° 34′.5 on the latitude arc; 9° 16′ N. on the declination arc, and mark the true meridian determined with the solar, by a cross on the stone already set 5 chains north of my station;

TO DETERMINE THE MERIDIAN.—*1st method:* Set up the instrument, set off the latitude and the corrected declination. A few minutes before the time of the observation bring the image into the field of view by moving the head of the instrument in azimuth and the solar telescope about its longitudinal axis. Clamp the head of the instrument. At the exact time of observation center the image by these two motions.

The telescope is then in the meridian.

THE TIME OF DAY, *when the meridian is known,* may be ascertained as described on page 226.

2d method: Set up the instrument, set off the latitude, the corrected declination, and, on the hour circle, the *local apparent time* of the observation. A few minutes before this selected time bring the image of the sun upon the equatorial wires by moving the head of the instrument in azimuth. Clamp the head of the instrument, and, avoiding all other motion, bring and keep the image accurately between the equatorial wires by turning the head of the instrument in azimuth by means of its tangent screw, until the image is centered upon the hour wire.

The telescope is then in the meridian.

REMARKS ON SOLAR INSTRUMENTS.—*First.* Solar instruments should never be used between 11 A. M. and 1 P. M. for measuring azimuths, and preferably not between 10 A. M. and 2 P. M. if the best results are desired.

Second. The nearer noon the instrument is used the greater the errors in azimuth due to erroneous settings of declination or latitude, being as much as 10′, in latitude 40° at 11:30, or 12:30, for an erroneous setting of 1′.

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this mark falls 0.3 inch *west* of the *true meridian* established by the Polaris observation.

"The solar apparatus, by P. M. and A. M. observations, defines positions for true meridians, about 0′ 11″ *east* and 0′ 16″ *west* of the meridian established by the Polaris observation; therefore, I conclude that the adjustments of the instrument are satisfactory.

"The *magnetic* bearing of the *true meridian*, at 8 hours A. M., is N. 18° 10′ W.; the angle thus determined, reduced by the table, page 100, gives the *mean magnetic declination* 18° 04′ *east*."

Third. At 6 o'clock A. M. and P. M., when the declination arm lies nearly at right angles to the meridian, a small change in the latitude will not appreciably affect the accuracy of the result.

Fourth. If the declination angle be erroneously set off and the co-latitude angle be also affected by *an equal error in the opposite direction*, then the two resulting errors in azimuth will tend to compensate. If, therefore, the declination angle be affected by an error, *and the latitude of the place then found by a meridian observation with the instrument, the error in declination will appear in the resulting co-latitude with the opposite sign.* In this way the effect of any constant error in the declination angle may be nearly eliminated.

The sun at a particular time having a fixed angular height in the heavens, we set this off on the instrument in two parts, one on the declination arc and the other on the latitude arc. Now, if we make an error and set off the declination *too great*, and an equal error *too small* in setting off the latitude, these errors will tend to balance each other and bring the line of collimation near its proper place, but will not do so *exactly* (because the planes of the two arcs are oblique to each other), except during the single instant when the sun is on the meridian, when the planes coincide and become one (Fig. 172). The declination and latitude angles bear a relation to each other similar to the two angles of a quadrant. If one is *too small*, the other will be *too large* by a certain amount, which errors become equal only when the sun is on the meridian.

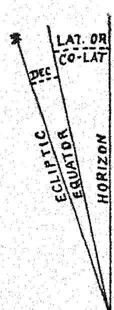

FIG. 172.

Fifth. The best times of day for using the solar attachment are from 7 to 10 A. M. and from 2 to 5 P. M. So far as the instrumental errors are concerned, the greater the hour angle the better the observation, but when the sun is near the horizon the uncertainties in the refraction may cause unknown errors of considerable size.

Sixth. For a given error in the setting for declination or

latitude, the resulting error in azimuth will have opposite signs in forenoon and afternoon.

As the sun at any particular time, say 9 o'clock A. M., has a fixed height in the heavens on any particular day, if the different angles are properly set off on the instrument, and the line of collimation turned upon the sun, its image will at that time be accurately centered between the proper lines on the silver plate, and the line of sight will lie in the true meridian; but suppose an error of 1′ too much be made in setting off the declination, then we will have set our line of collimation too high for the position of the sun at 9 o'clock, and it will not, when the instrument is in the meridian at 9 o'clock, center properly between the lines, but obliquely above; consequently, if we have clamped the hour circle at 9 o'clock, we must wait some time for the sun to reach the height that we have set off on the instrument for it before it will be properly centered. If we do center the image at 9 o'clock, it will be by turning our instrument slightly from the position it should occupy, and our line of sight will not lie in the meridian, but to the west of it, if looking south, or east of it, if looking north, by 1′.85 for latitude 40°. In the *afternoon* the converse will be true.

Seventh. If the adjustments are not carefully attended to, the error in the bearing of a line may be much greater when taken by the solar attachment than is likely to be made by the needle when there is no local attraction.

When the sun is on the equator, September 22d and March 20th, the declination arm will be perpendicular to the polar axis, and the zero of vernier will coincide with zero of declination arc. From March 20th to September 22d, the sun being above the equator and consequently above the equatorial plane, its rays will pierce the equatorial plane from above, and the relative positions of the declination arm, equatorial plane, polar axis, and horizontal plane will be as in Figure 170*a*. From September 22d to March 20th, the sun being below the equator, its rays will pierce the equatorial

plane from below, and the relative positions of the declination arm, equatorial plane, polar axis, and horizontal plane will be as in Figure 170*b*. When the declination arc is graduated in but one direction from the zero of the scale, then it is necessary to have on each block a lens and silver plate, or, in other words, to have two lines of collimation; and it is necessary to revolve the declination arm from the position shown in Figure *a*, which is for north declination, to that shown in Figure *b*, for south declination. If, however, the declination arc is graduated in both directions from the zero of the scale, then but one line of collimation is necessary.

THE TIME OF DAY, *when the meridian is known*, may be approximately ascertained with the solar attachment by setting the telescope in the meridian, then setting off the co-latitude and approximate declination and bringing the image of the sun between the hour lines by moving the declination arm in hour angle only; then the index on the hour circle will show apparent time, which can be reduced to mean time. It is best ascertained, however, when the sun is on the meridian, the time thus given being that of apparent noon, which can be reduced to mean noon by adding or subtracting the *equation of time*, as the sun is slow or fast.

CHAPTER XIII.

THE SEXTANT.

DESCRIPTION.—The Sextant (Fig. 178) is a hand instrument for measuring angles, up to 120°, subtended by any two objects, the angle being in the plane through the instrument and the two objects. It consists of the following parts—viz., a mirror I (Fig. 179) called the *index glass*, rigidly attached to a

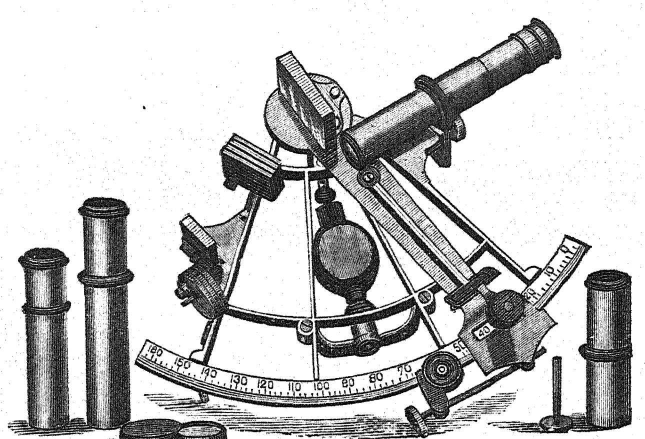

FIGURE 178.

movable arm A called the *index arm*, and a mirror H called the *horizon glass*, rigidly attached to the frame of the instrument. The lower half of the horizon glass is silvered while the upper half is clear. Both mirrors should be perpendicular to the plane of the graduated limb C.

The arc of the limb is about 65° or 70° long, graduated to degrees, half degrees, etc., each half degree being numbered as a whole degree so the reading will be the angle subtended by the objects. On the extremity of the index arm is a vernier V. Opposite the horizon glass is a telescope T. Colored glasses are provided for neutralizing the sun's rays, and a magnifying glass for reading the vernier.

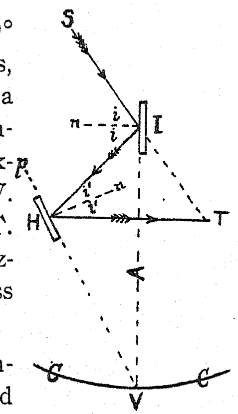

FIG. 179.

THEORY.—The principle of its construction is that a ray of light reflected at two plane surfaces in a plane normal to both is deviated from its original direction through an angle double that made by the two reflecting surfaces. Thus a ray of light from S to T being reflected at I to H, and again reflected at H to T, the angle STH between the original direction ST and the direction after the second reflection HT is double the angle IVH between the mirrors. For, drawing the normals n, n, to the mirrors and representing the angles of incidence and reflection at I by i and at H by i', as in the figure, in the triangle ITH the exterior angle

$$2i=2i'+\mathrm{T},$$
$$\therefore \mathrm{T}=2i-2i',$$
$$=2(i-i'),$$

and in the triangle HVI the exterior angle

$$\mathrm{IH}p=90°-i',$$
$$=\mathrm{HIV},$$
$$=(90°-i)+\mathrm{V},$$
$$\therefore \mathrm{V}=(90°-i')-(90°-i)=i-i',$$
$$\therefore \mathrm{T}=2\mathrm{V}.$$

WHERE USED.—The sextant (Fig. 178) is the one principally used at sea in observing the altitude of the sun and lunar distances, to determine the latitude and longitude, where the unstable position of the mariner excludes the use of almost al other instruments. On land it is one of the most

convenient, accurate, and generally useful instruments with which to obtain data for the solution of a variety of astronomical and other problems.

THE POCKET SEXTANT (Fig. 180) is the one most frequently used in reconnaissances, preliminary surveys, and explorations.

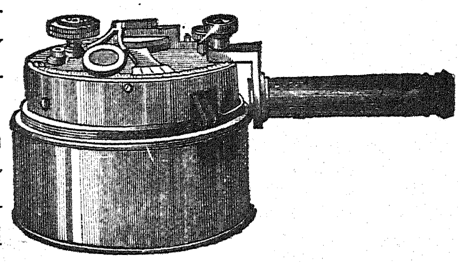

FIGURE 180.

Description. It is, in construction, exactly like the larger one, except that the mirrors and colored glasses are enclosed in a cylindrical box $2\frac{1}{2}$ to 3 inches in diameter and $1\frac{1}{4}$ to $1\frac{1}{2}$ inches high, with suitable openings in the side for exposing the mirrors. The index arm is worked by a milled-head screw and revolves on top of the box on which is the limb. The vernier reads to 1 minute. The telescope, when not needed, may be taken out, and a slide having a small peep-hole may be pushed over the opening. The adjustments are made by means of a key in holes provided on top and on the side of the horizon glass. The cover is screwed on the bottom of the box, serving as a kind of handle in making observations. The pocket sextant is used the same as the larger one.

The advantages of the pocket sextant are its accuracy and portability. When one's exact position is not material it can be readily used on horseback, in a tree, or wherever it may be necessary to take an observation. It is not affected by magnetic disturbances like the compass needle.

The disadvantages are, that it cannot be generally used in traversing and other surveying operations, but is limited to measuring minor angles in triangulation, finding one's place on a map, and determining heights and distances.

ADJUSTMENTS.—*1st adjustment: To make the index glass perpendicular to the plane of the graduated arc.* Test by setting the vernier at about the middle of the graduated arc,

then holding the eye near the plane of instrument and looking into the index glass and at the arc, if the arc and its image appear to form one continuous arc, the adjustment is correct; if not, adjust by screws at the back until they appear continuous. In the pocket sextant the index glass is fixed to index arm and is not adjustable.

2d adjustment: To make the horizon glass perpendicular to the plane of the limb. To test, having made the previous adjustment, hold the instrument horizontally and sight on some well-defined distant vertical object, as the corner of a chimney, or, holding the instrument vertically, sight on the horizon and bring the direct and reflected images into coincidence; i they remain continuous when the instrument is tilted, or if by a sweep of the arm the reflected and the direct images pass accurately over each other, the horizon glass is perpendicular to the plane of the instrument; if not, it must be made so by the adjusting screws at the back. With the pocket sextant this adjustment is done with the key in the holes on top of the horizon glass.

3d adjustment: To make the line of collimation of the telescope parallel to the plane of the arc. Rest the sextant on a plane surface, pointing the telescope upon a well-defined point about 20 feet distant. Place two objects of equal height upon the extremities of the arc, that will serve to establish a plane of sight parallel to the arc; two lead pencils of the same diameter will serve, but they should be of such height as to make this plane of sight the same height above the arc as the line of collimation of the telescope. If the line of collimation intersects the line defined by the two pencils, then the instrument is in adjustment; if it does not do so, then correct by the screws on the telescope holder.

4th adjustment: To correct the index error. Sight on some well-defined distant object (preferably a star), moving the index arm until the direct and the reflected images are coincident; if the vernier reads zero, the instrument is in adjustment; if not, the reading is the index error of the instrument

and may be corrected, or simply noted and applied to all readings.

ARC OF EXCESS.—The graduations on the arc are continued some 10° to the right of the 0 of the scale; this is called the "*arc of excess.*" If, when the mirrors are parallel, the 0 of the vernier is on the arc of excess, then all angles will be measured from this point and will be read too small and the index error must be added, since the zero is "off" the scale. If, however, the zero is "on" the scale when the mirrors are parallel, angles will be read too great and the index error must be subtracted. In reading the index error "off" the arc, it must be remembered that the amount is the distance on the scale from its zero passed over by the zero of the vernier, but as the vernier is only constructed to read in one direction, when reading the vernier off the arc the number of least reading units must be subtracted from the smallest reading of the scale and this remainder added to the reading on the scale for the index error.

TO USE THE SEXTANT.—*To measure any angle*, the instrument is held in one hand in the plane of the two objects. The telescope is directed towards the *fainter object* through the unsilvered portion of the horizon glass. With the other hand the index arm is moved until the other object, seen by double reflection in the lower part of the horizon glass, is brought into exact coincidence with the object seen direct. The reading of the vernier is the required angle. If the fainter object is to the right, the instrument will have to be held upside down.

If the horizontal angle between two objects of different elevations is desired, some object is found by a plumb-line, or otherwise, directly above or below each and in a horizontal plane through the instrument, and then the angle measured.

If the angular distance between the two objects *is very small*, then the angle between each and some third object in line with them may be measured and the difference taken. If greater than the range of the instrument, the sum of the

angles between each and an intermediate object will be the angle required.

Where one of the objects is near the observer, it is better to sight at this one directly and bring the distant one into coincidence by reflection, to reduce the effect of *parallax* as much as possible; parallax being the angle subtended at the reflected object by the distance between the observer's eye and the center of the index glass.

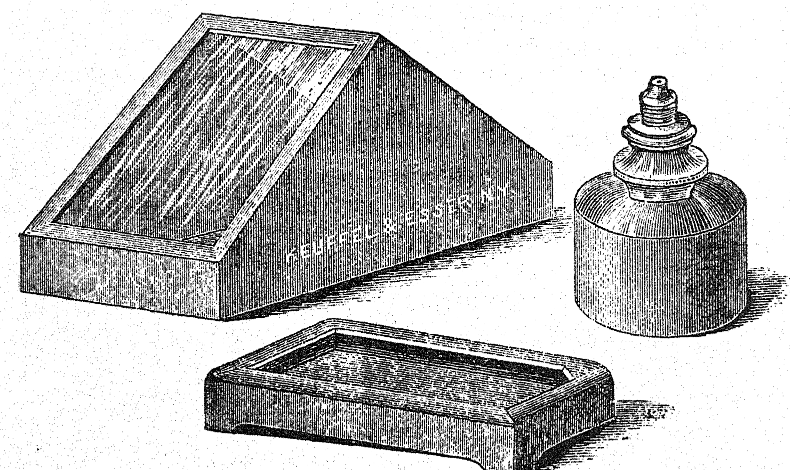

FIGURE 181.

Artificial horizon. With the sextant on land there is used, in observing altitudes, what is called an artificial horizon (Fig. 181). This may be mercury, oil, or water placed in a small shallow dish so as to furnish a horizontal reflecting surface. A glass cover is ordinarily used to protect the surface from wind and dust in making the observation. The angle obtained is double the altitude of the object, since it is the angle at the eye subtended between the object and its image in the artificial horizon.

Suppose (Fig. 182) O a distant object, as the sun, moon,

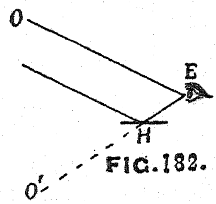

FIG. 182.

or star, E the eye, and H the artificial horizon. A ray from O is received at E, a parallel ray strikes the surface of H and is reflected to E, giving the appearance of the object O at O′. Now with the sextant looking directly at the reflection of the object in the artificial horizon and bringing the double reflection of the object into coincidence with it, the angle OEO′ is measured, which is double the altitude.

In making observations upon the sun and moon it is to be remembered that the artificial horizon inverts as well as the telescope, and since it is preferable to measure its altitude by getting the altitude of the upper or lower extremity of the vertical diameter and adding or subtracting the semi-diameter for the altitude of the center, attention must be paid to the appearances of the images in the instrument. After getting the images in contact, if, by moving the arm outward, the lower image passes over the other, then the lower limbs were in contact, since the double reflected image was below. If, however, they separate, then the upper limbs were in contact, for the image reflected from the mercury finally appears erect to the eye, while the image from the mirrors is inverted and was above, and by moving the arm it is the one affected.

Measuring depressions and low altitudes. In measuring low altitudes and depressions some means must be arranged for establishing a vertical plane. This is frequently done by stretching a string about 3 feet above the artificial horizon and so placing the eye that when looking through the telescope vertically down on the string it will hide its reflection, then bringing the double reflection of the object into coincidence with the string. The difference between the measured angle and 90° will be the angle of elevation or depression.

Latitude with the Sextant. The double altitude of a star is measured directly by bringing the direct and the reflected images into coincidence. Then take ½ the double altitude, correcting for refraction and pole distance, for the latitude.

The altitude of the sun when on the meridian may be observed with either the mariner's or the pocket sextant, and from it the latitude of the place be determined as previously explained.

PROBLEMS.—1. *Resection with the Sextant.* Having three visible points, A, B, and C, plotted on a map in *a*, *b*, and *c* to find one's place *x*. (Fig. 183.) Observe with the sextant, at X, the angles AXB and BXC. Since through any three points, as A, X, and B, or B, X, and C, not in a straight line, a circle may be drawn, and since an angle at the center (O or O′) of a circle is double an angle on the circumference at *x*, including the same arc of the circumference *ab* or *bc* as the angle at the center, the unknown point *x* may be found and plotted.

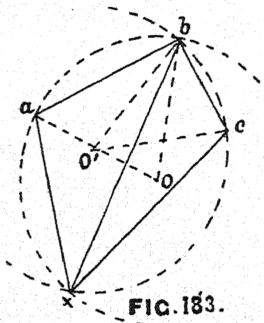

FIG. 183.

The operations consist in finding the centers O and O′, drawing the circles, whence one of their intersections will be the plotted point of X. To find the center O, double the angle AXB, subtract result from 180°, divide remainder by 2; at *a* and *b* lay off from the line *ab* this quotient *bao* and *abo* and the intersection of the sides will be O. To find O′, double BXC, subtract result from 180°, divide remainder by 2, and lay off at *b* and *c* from the line *bc* the quotient, *cbo′* and *bco′*, the intersection of the sides being O′. The sum of the three angles of a triangle being 180°, double the angle observed at X being equal to the angle at the center O, then the other two angles of the triangle, as at *a* and *b*, must each be equal to the quotient laid off.

Should either or both of the angles observed at X be greater than 90° (Fig. 184), the center of the circle to be constructed will be on the opposite side of the chord, joining the plotted points, from the required point X. To find the centers in such cases,

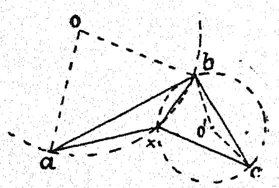

FIG. 184.

use the supplement of the observed angles, double, subtract from 180°, etc., and construct as explained.

2. *To set off a perpendicular to a line.* Set the index at 90°. Hold the sextant over the point of the line. When looking along the line, find or have set a stake coinciding by reflection with the line and it will be in the required perpendicular. Similarly, *to find where a perpendicular, let fall from a point without, intersects the line.* With the index at 90°, walk along the line until some point of it is found where the direction point of the line and the given point coincide.

3. *To measure the distance to an inaccessible object.* Let B (Fig. 185) be the inaccessible object whose distance from A is desired.

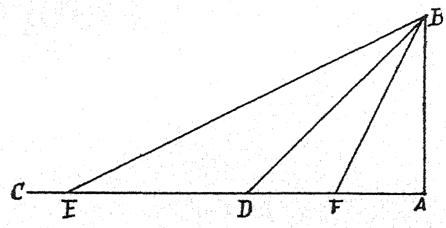

FIG. 185.

At A find with the sextant a distant object C in a line perpendicular to AB. Then set the sextant at 45° and move along AC until the point D is found where A and B coincide. Measure AD; it is equal to AB. With the sextant set at 26° 34′ AB will be $\frac{1}{2}$ AE, and with it set at 63° 26′ AB will be twice AF. The following table gives a few angles at which to set the sextant, and corresponding multipliers of base to obtain the required distance:

14° 2′ = $\frac{1}{4}$.	18° 26′ = $\frac{1}{3}$.	26° 34′ = $\frac{1}{2}$.	45° = 1.
63° 26′ = 2.	71° 34′ = 3.	75° 58′ = 4.	

4. *To find the height of an object on level ground.* Suppose AB to be a vertical object the height of which is desired, and AC level ground. Make a mark on the object at the height of the eye, set the index at 63° 26′, 45°, or 26° 34′, and move back until the mark and the top of the object coincide in the sextant, when the height above the mark will be twice, equal to, or one-half the distance moved back, and, adding the height of the eye, the height of the object is obtained.

5. *To find the height of an object on level ground, but inaccessible at the base.* (Fig. 186). Find a point D where the top of the object A and a point B, the height of the eye, coincide in the sextant set at the angle of 26° 34′. Mark the point D. Set the sextant at 45° and move towards the object on the line BD until A and B again coincide. The point reached will be C; mark it and measure CD; it will be the height AB, to which add the height of the eye for the height of the object.

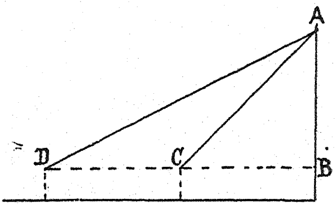

FIG. 186.

If for any reason it is impossible to use the point C in the line BD, but it is possible to find a corresponding point in a line at right angles to BD, then at D observe the angle subtended by AB (Fig. 187). Find some distant object E in a line perpendicular to BD. Set the sextant at the complement of the angle observed at D and move along the line DE until the point C is reached, where B and D coincide. Measure DC and it will be equal to AB; to this add the height of the eye for the height of the object. This method is the more general one and is independent of fixed angles.

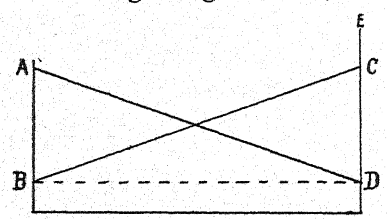

FIG. 187.

6. *To measure the distance between two points, both inaccessible.* (Fig. 188). At any point A measure the angle BAC. Set the sextant at ½ this angle and move back from A keeping aligned on C till B and C again coincide, then DA will equal BA. Similarly find E such that AE will equal AC, then DE will equal BC.

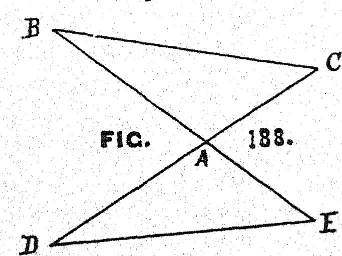

FIG. 188.

CHAPTER XIV.

THE ANEROID BAROMETER.

DESCRIPTION.—For determining approximate differences of elevations of points on reconnaissances and explorations, and sometimes in traverse work, the *aneroid barometer* (Fig. 189) is used. It consists of a flat cylindrical box of thin elastic metal with a corrugated top which communicates with an index through a train of mechanism. The box is nearly exhausted of air before being sealed, only enough being left in to resist or compensate, by its expansion, the increased pressure of the air on the greater surface of the box at higher temperatures. In some aneroids one of the levers is made of two metals (brass and steel) which expand and contract differently. This compensation for temperature simply refers to the instrument itself, freeing it from errors arising from changes of temperature, and in no way refers to the difference of temperature at the different points of observation, which must always be taken into account.

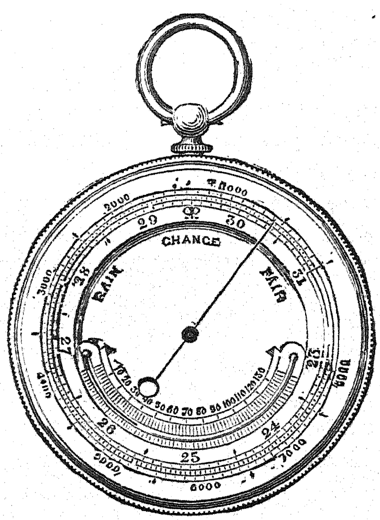

FIGURE 189.

The index moves over a dial having graduated on it either a fixed scale of inches and a revolving altitude scale; or, both the inch and altitude scales are fixed, and there is a re-

volving vernier scale. The usual altitude scale is a gradually diminishing one, but to enable a vernier to be used the interior action of the instrument has to be adjusted so as to give accurate readings upon a uniform altitude scale, and the scale of inches, which is usually uniform, has to be made progressive.

Several sizes are made, the $2\frac{1}{2}$-inch being the most satisfactory. Owing to its extreme delicacy, it is a very uncertain instrument and should be used for only small differences of elevation and small intervals of time. Its indications should be checked by reference to known elevations whenever opportunity is afforded during the day, and at the beginning and ending of each day's work.

USE OF THE ANEROID.—What the aneroid actually does is to weigh the pressure of the atmosphere at the time of reading it in terms of a mercurial column expressed in inches and decimals; hence before the dial is graduated it is compared with a standard mercurial barometer. It does this by the rising and falling of the corrugated top, under different pressures, which rise or fall is multiplied several hundred times before being communicated to the point of the index. Since by means of *barometric formulæ* relative elevations may be obtained with the mercurial barometer after making certain corrections and reductions in the readings for *temperature, humidity, latitude, and gravity,* so the readings of the aneroid can be used in the same way for the determination of relative elevations, which is its principal use. Since the pressure of the air at any place varies considerably at different times from various causes, though no difference of elevation has taken place, all changes in readings cannot therefore be due to changes in elevation. But if two barometers, which have been adjusted and compared, be read at the same time at two points not too distant, of different elevation, under the same conditions, etc., then from these readings the difference of elevation of the points may be determined very closely. If the points be very distant, a long series of observations must

be made to clear the results of local changes before the difference of elevation can be obtained.

Airy's Tables are prepared to show differences of elevation corresponding to different readings for a mean temperature of 50° F.; hence, if the mean temperature differs much from 50°, to determine the difference of elevation of points, the temperatures at the two points must be added together, and if the sum is greater than 100° F., the difference of elevation as obtained must be increased by its $\frac{1}{1000}$ part for every degree in excess; if less than 100° F., it must be diminished by its $\frac{1}{1000}$ part for every degree less.

A convenient formula under altitudes of 3,000 feet, giving approximate differences of elevations without the use of tables, is $D=55{,}032\frac{H-h}{H+h}$ for a mean temperature of 55° F., in which H and h are the barometric readings in inches. For other temperatures apply $\pm\frac{1}{435}$ of itself for each degree above or below.*

*When using but one instrument, Mr. Chas. A. Ashburner, Geologist of the Second Geological Survey of Pennsylvania, sometimes used the method originated by him of passing in the forenoon between stations as rapidly as possible, stopping at a number of them for half an hour or so, reading the barometer on arriving and leaving, and in the afternoon returning over the same route, repeating the operations. The difference of the two readings at any station indicates the rate of change for that time. From these isolated rates of change, on the assumption that changes between stops were regular, he constructed a continuous correction curve for the day on profile paper (Fig. 190), from which he obtained, by scaling, the probable corrections to be made to the reading, due to changes in atmospheric pressure, to obtain the correct altitudes or differences of elevations. For constructing the curve the *scale of time* is taken horizontal, the interval of time between the verticals being 30 or 60 minutes. The *scale of feet* (difference between readings during stops) is taken vertical, the inter-

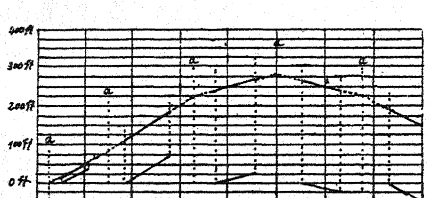

FIG. 190.

Precautions. In using the aneriod it should be kept in the case so as to be protected from sudden changes of temperature, the influence of the heat of the hand, or body, or sun; before reading, it should be swung backwards and forwards, or the glass cover tapped, to overcome any friction of its parts; it should always be held, preferably horizontal, at a constant height from the ground when being read.

Advantages. The aneroid is more portable and indicates changes of atmospheric pressure more quickly than a mercurial barometer, for which reasons it is particularly adapted to reconnaissance and exploration surveys.

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val between horizontal lines being 5, 10, or 25 feet. The changes at each stop are first plotted from the zero horizontal line between the times they were made; thus, if at a stop between 8:30 and 9:06 A. M. a difference of reading of 25 feet occurred, on the zero line at 8:30 o'clock a straight line would start and rise to 25 feet on the 9:06 o'clock vertical, and so for all other stops. The hour distances between stops are then bisected (*a*) and verticals erected at these points. Beginning where the first bisecting vertical intersects the zero horizontal, a line is drawn parallel to the profile of the change at first station to the second bisecting vertical, then from here another line is drawn, parallel to the profile of the change at second station, to the third bisecting vertical, and so on. The profiles of the changes first plotted are then projected vertically upwards on the broken line just drawn between the bisecting verticals, and the extremities of the profiles thus projecting upwards are then connected by a curved line to represent the changes in the barometer readings between stops due to changes in the atmosphere. The corrections to be made to the barometer's reading at any station may now be obtained directly from the correction curve.—*Haupt.*

PART II.

Topographical Sketching.

CONTENTS.

PART II.—TOPOGRAPHICAL SKETCHING.

CHAPTER XV.

MEASUREMENT OF DISTANCES.

It is only after considerable study and practical experience with instruments of precision that the topographer can hope to make a comparatively accurate graphical projection (or sketch) without their aid. Before proceeding to the explanation of topographical sketching, it will be necessary to consider the instruments used in and the methods of measuring distances, angles, and elevations, in the same order as in more accurate work.

TELEMETERS OR RANGE-FINDERS.—These instruments are called telemeters (distance-measurers) and range-finders indiscriminately. If used to determine *distances*, when making a *survey or reconnaissance*, they are called telemeters; but if used to determine *ranges* on the field of battle *for firing*, they are called range-finders.

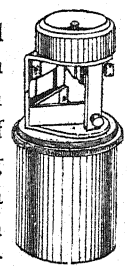
The importance of determining accurately the distances to objects in sketching is becoming more and more necessary. The estimation of distances by eye, with even approximate accuracy, over familiar ground and at short ranges is a difficult matter. To do so over varied and unknown ground and at longer ranges is so difficult and gives results so unreliable as to be almost useless for practical purposes.

The following points are desirable in Telemeters to make them applicable for all military purposes: cost moderate, construction simple, absence of delicate manipulation, not easy to get out of adjustment but capable of being re-adjusted, easy to learn to use, not easily damaged but easily repaired, weight light, size small to be held and used in the hands, giving ranges quickly either directly or by a simple multiplication or

division, not requiring over two men, requiring short base, capable of being used kneeling or lying down.

Telescope Telemeters, consisting of *micrometer eye-pieces* fitted to ordinary telescopes, are useless for practical purposes and are classed as optical curiosities.

The *principle* upon which the following range-finders are constructed is that of measuring the base and the two adjacent angles of a triangle, and then partially solving the triangle, the distance or range being the required side.



PRATT.

The Pratt consists of a triangular frame holding two pairs of mirrors capable of being adjusted to certain angles by means of adjusting screws. On top of the frame is attached a small compass. In the back of the frame, between the two pairs of mirrors, is a small rectangular opening for sighting through. The frame is screwed for use on top of a cylindrical case, in which it is carried when not in use. On the bottom of the case is a small ring for attaching a plumb-line. The upper pair of mirrors is set at an angle of 45°. The lower pair is generally set at 44° 17′ 02″, the tangent of twice which is 40, though it may be set at one-half of other angles, as 87° 08′ 15″, 88° 05′ 27″, or 88° 51′ 15″, whose tangents are 20, 30, or 50, respectively. Weight is 2.1 ounces.

To adjust the instrument: Set up a transit over a marked stake. Find two small well-defined distant objects, or set range poles at 90° from each other; also two objects, or set range poles at 88° 34′ 04″ from each other. Stand over the transit stake with the instrument and by means of the adjusting-screw of the upper pair of mirrors bring the two objects 90° apart into coincidence, one seen through the opening and one by reflection; then by means of the lower adjusting-screw bring the two object 88° 34′ 04″ apart into coincidence. Repeat for a test.

The principle of its construction is similar to that of the sextant—*i. e.*, that by reflection at two plane surfaces, a ray of

light is deviated through an angle double that made by these surfaces.

The instrument requires occasional testing, as a change of only 3′ in the angle of a mirror will introduce an error of $7\frac{1}{2}$ per cent of the length of the range. The necessity for frequently testing the adjustments is a fault. The mirrors are too small. The effect of temperature, although undetermined, is to change the angles between the mirrors.

In determining a distance with this instrument there are used two fixed angles, and a base whose ratio to the distance required is also fixed.

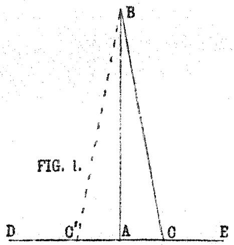


FIG. 1.

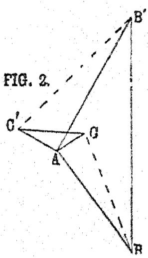


FIG. 2.

To determine a distance A B (Fig. 1), it is held vertically over A; the operator, looking toward B directly through the opening between the pairs of mirrors, turns it until a well-defined line on some distant object D (called the *direction point*) is seen by reflection in the upper pair of mirrors in coincidence with some well-defined line of B. The angle subtended by these two lines will be twice that between the mirrors, or 90°. Then placing a stake vertically in the ground at A, he moves off to the right towards E, keeping aligned on A and D, until a point C is reached at which, looking at D through the opening, the lines on B and D before selected again coincide (B by reflection) in the lower pair of mirrors. Measure AC and multiply by the tangent of twice the angle at which the lower pair of mirrors is set, 40 in case above, and the product will be the distance sought. Care must be taken that vertical objects appear vertical when reflected.

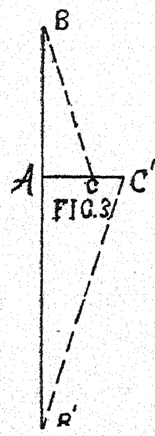
A base to the left of A may, if more convenient, be used by taking a direction point to the right, as E, and looking into that mirror of each pair not looked into with the base to the right; or, D may be viewed directly and B seen by reflection.

By observing the caution to select the *distant* object D as the direction point, very slight departures from the line AD in moving to C will not materially affect the angle BCD; were D near A, the result would be different.

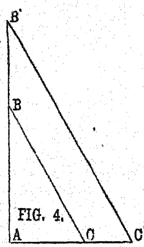
The movement from A away from D enables the observer to align himself on A and D.

It may also be used for determining the *distance between two inaccessible objects*, as B and B′ when standing at A.

1st. When the observer is *not* on BB′ (Fig. 2, p. 245) proceed as if to determine the distance AB, as previously explained, simply marking the extremity C of the base AC, without measuring it. Then proceed as if to determine the distance AB′, again simply marking the extremity C′ of the base AC′; now measure CC′, and multiply by the multiplier for which the instrument is set, and the product will be the distance BB′. In cases like this, where the observer is not on the line BB′, it is necessary that the direction of both the bases AC and AC′ be taken to the same side of A—that is, both to the right or both to the left of A when facing the distant station. In other cases this is not essential.



2d. When the observer is *on the line* between B and B′ (Fig. 3), the sum of the bases AC and AC′ is used with the multiplier for the distance BB′. If on the line, but below both B and B′ (Fig. 4), then the difference of the two bases is used with the multiplier.

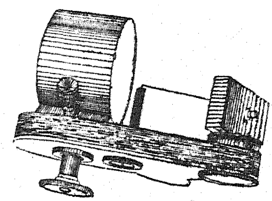


With two observers, two instruments, and a tape-line, the distance of a *moving object* may be determined. The two observers face each other. One holds the end of the tape and brings the other and object into coicidence in the upper pair of mirrors by moving to right or left. The other observer, by moving backwards or forwards, brings the first observer and the object into coincidence in the

lower mirror; when by concert of action both have the coincidence at the same time, the distance between them is the base to use with the multiplier.

GREEN

The Green consists of two pairs of mirrors mounted in a frame as shown, one pair, marked 1 on the back below the two screws seen in cut, being set at 45°, and the other pair, marked 2, being set at 44° 25′ 37.5″. It is also provided with a ball-and-socket joint and a strap for fastening on the wrist. This instrument is used in the same manner as the Pratt. The multiplier, however, is 50 instead of 40.



GORDON.

The Gordon consists of a horizontal bed on which are mounted two small mirrors $2'' \times 1''.2$, both vertical and capable of adjustment like the glasses of a sextant; it has a ring for attaching it to an object-glass of a binocular, the field of which is thus half covered by one of the mirrors.

This mirror can be moved slightly around a vertical axis by a nut below the horizonal plate which turns a cam, operating on a lever; a graduated disk underneath gives the reading. The disk is graduated from 0 to 250 and revolves 360°, while the mirror revolves but 3°, from 45° to 48°. Weight, 2.5 pounds.

To determine the distance AB (Fig 1, p. 245), set the disk at 0 and so as to give increased readings as it revolves. This sets the mirrors at 45°. With them above the horizontal plate at A, sight over the mirror at a distant direction point D (Fig. 9), and find a well-defined line or point of it which coincides with a line of B, the latter seen by reflection. Then move from A towards D to a point C′ on the line AD; the length AC′ should increase as AB increases. At C′, again sighting towards D, turn the disk

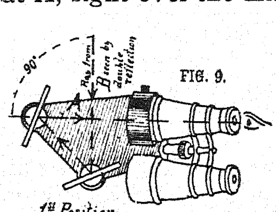


FIG. 9.

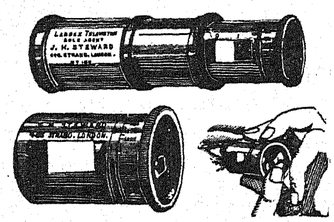
until the lines B and D are again brought into coincidence. Take the reading of the disk and measure AC′. Divide the latter by the disk reading and multiply the quotient by a number corresponding with the disk reading, which is found in a table furnished with each instrument.

A base to the right may be used by sighting towards B and finding E by reflection.

The principle of its construction is similar to that of the sextant. With one fixed angle, 90°, a varying obtuse angle DC′B and a varying base are used. By taking certain of the varying angles the ratio of base to distance may be fixed as in the Pratt.

A single observer must virtually select two objects on which to align himself as he moves from A to C′.

The Labbez consists of two plane mirrors set in a cylindrical tube, the front end of which is partially, and the rear end entirely open.


LABBEZ.

The principle of its construction is similar to that of the sextant. The front or horizon glass has a movement, around a vertical axis, of 4° by means of a small toothed wheel on the front end. The rear or index glass has a movement of 5° by turning the front end of the tube. With both glasses at 0°, the angle between them is 45° and may be varied between 43° and 47° by moving the toothed wheel. Keeping the toothed wheel at 0° and turning the front end of the tube, the angle will vary between 45° and 50°.*

* Were the mirror set at 47½° at A, with D′ for the direction point, the instrument should read 1,809.5 yards for a distance AB of 1,800 yards, and 504.5 yards for AB of 500 yards using 30 yards base. The reason for this is, having moved the toothed wheel 2½° until B when reflected coincides with D′, and having moved 30 yards to C′, if now D′ be sighted again, an object at B′ should coincide with it, B′C′ being parallel to AB. To bring B into coincidence again with D′ the index mirror must be moved over ½ the angle BC′B′, or practically the angle

Accompanying it is a line 30 *yards* in length, used for measuring the base. The ranges corresponding to the various positions of the index-glass are marked on the cylinder of the revolving end. This instrument is made in two sizes, to both of which telescopes may be attached. Distances may be determined with them from 250 to 3,000 and 5,000 yards, respectively. Weight of smaller size with telescope, $6\frac{1}{2}$ ounces; with both line and case, 11 ounces.

To determine a distance AB (Fig. 5), open the slide on the front end. Set both mirrors at 0. Look through the instrument over the mirrors for a direction point D coinciding with the reflection of B. If none such be available, either set one at any distance over 60 yards, or move the toothed wheel on front end to right or to left until a direction point D′ or D″ is found. Fasten one end of the line at A, move 30 yards toward the direction point to C, C′, or C″, where, facing the direction point as at A, turn the head of the cylinder until coincidence with B is again obtained. The required distance in *yards* is then read off the cylinder.

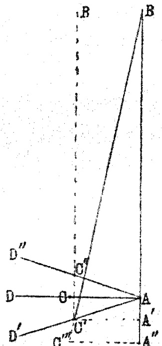


FIG. 5.

For distances over 1,000 yards, use 60-yard base and multiply readings by 2; over 2,000 yards, use 90-yard base and multiply readings by 3.

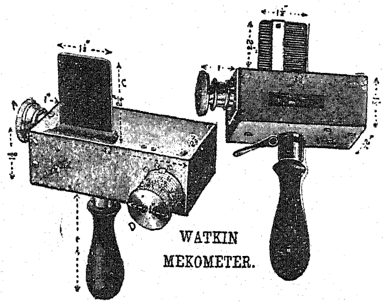
C′BA is measured. Now C′A′, a perpendicular to BA prolonged, is less than AC′, or less than 30 yards; produce BA and BC′ to A″ and C‴, respectively, the distance A″C‴ being 30 yards long and perpendicular to BA. Then will AA″ be the error in distance corresponding to the angle C′BA. With a base of 1 to 100, the maximum error is said to be about 1 in 30; with a base of 1 to 50, about 1 in 70; so the errors due to the toothed wheel are within the maximum errors of the instrument.

$$BA'':C'''A''::BA':C'A' \text{ or } d+E:b::d+b \text{ sin. } a:b \text{ cos. } a; \text{ hence}$$

$$E = \frac{d \pm b \sin. a}{\cos. a} - d,$$

in which E = error, d = true distance, b = base, a = angle by which b departs from being perpendicular to d; upper sign for D′, lower for D″.

The Watkin Mekometer consists of two rectangular aluminum boxes, one for each end of the base. Each box has two mirrors inside, and is fitted with a removable handle, a small telescope, and on top a folding flap on which is an ivory strip. Accompanying each box is a reel on which are wound two cords, each $12\frac{1}{2}$ *yards* long, and having a spring hook on each end. One instrument,



WATKIN MEKOMETER.

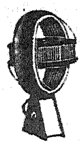
known as "the right" or "No. 1," is the larger and views the object directly through an opening in the end, and the ivory of "the left" or "No. 2" by double reflection from the two mirrors through an opening in the left side. A drum on the right side, engraved with distances in *yards*, when revolved, slightly changes the angle of the mirrors inside and allows an exact coincidence of the object and the ivory of "the left." The reading on the drum opposite the fixed index gives the distance in *yards*. Weight $1\frac{1}{2}$ pounds. "The left" or "No. 2" instrument has no drum and the angle of the mirrors is fixed at 45°. With it the object is viewed directly through the telescope, and the ivory of "the right" by double reflection from the mirrors through an opening in the right side. Coincidence is obtained by moving backwards or forwards. Weight 1 pound.

To determine a distance AB (Fig. 1, p. 245), both observers screw in the handles, hook the ends of their cords together, and separate until 25 yards apart (2 cords), then attach the other ends of their cords to the hooks on the handles. The flaps are raised. The left observer, "No. 2," places himself in the right angle at A by moving backwards or forwards until the object seen by direct vision is coincident with the ivory of "No. 1" seen by double reflection. The right observer, "No. 1," at C, then brings the object and the ivory of "No. 2"

into coincidence by turning the drum, and reads off the distance. If the distance of the object is greater than 1,500 yards, a base of 50 yards (4 cords) is used, and the readings on the drum doubled. If the distances are short and space restricted, a base of $12\frac{1}{2}$ yards (1 cord) is used, and the readings on the drum halved.

If the object observed is moving, "No. 2" swings his body, backwards if the object is moving from right to left, or forwards if from left to right; and keeps exact coincidence while "No. 1" is obtaining coincidence with the drum of his instrument.

Of the mirror instruments described, the Pratt and Green can be considered as having fixed angles.*



WELDON.

A couple of prism instruments, having fixed angles, will now be described.

THE WELDON† (original pattern) has three glass prisms. Two of these prisms, one having an angle of 90°, the other 88° 51′ 15″, are cemented together back to back in a ring $\frac{1}{2}$ inch thick and

*A pocket sextant in adjustment or of known index error may be used for determining distances by setting it successively at the same angles as are used in the Pratt and Green.

†A ray of light passing from air into glass is refracted (bent from its original direction) and makes in the glass a less angle with the normal (perpendicular) to the surface of entrance than it did in the air. Again, no ray of light lying in a plane perpendicular to the face of a prism will pass, by two refractions only, through any prism whose prism angle is greater than twice the greatest possible angle which the ray can make, *in the glass after refraction*, with the normal, but will be reflected at the inside surface of the second face. This angle, called the *critical angle*, is about 42° for glass. Since this angle of 42° is the greatest angle which a refracted ray in a prism can make with the normal after it has entered, it follows, as emerging rays follow the same law regarding critical angle as entering rays, that it is also the greatest angle of incidence which a refracted ray in a prism can make with the normal and still emerge from the prism. Hence, if a ray of light enters and is refracted at one face of a prism and then falls on another face of it at an angle with the normal to that face greater than 42°, it can not pass out, but must be reflected by that face. Further-

$1\frac{1}{2}$ inches in interior diameter and revolve on a diameter of the ring. The third has an angle of 74° 53′ 15″, and is cemented in the handle. The shape of this instrument admits of its being carried in the pocket. It weighs but 4 ounces, is not subject to derangement, and gives greater clearness of image than the mirror instruments.

To determine a distance AB (Fig. 6, p. 253). Standing at

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more, if a third face of the prism be silvered, incident rays at any angle will be reflected by it.

As two of the prisms have angles greater than twice 42°, the refracted rays used suffer other changes of direction in the prisms, due to reflection. Though the angle of the third prism is less than twice 42°, the frame intercepts the passage of those rays which would suffer doubled refraction only.

Now follow a ray of light from any object B (Fig. 10). Striking the outside of the first face of the prism, it enters, and is refracted in the prism, strikes the inside of the second face, but at an angle with the normal greater than the critical angle; hence, instead of passing out again, it is reflected by the second face to the silvered third face, where it is again reflected back to the inside of the second face, but at a less angle with the normal then the critical angle; hence it can pass out of the prism into the air, where it is again refracted, making the same angle with the normal to the second face that it did with the normal to the first face before entrance. Should a ray strike the first face normal to it and emerge normal to the second face, it would have been deviated through an angle equal to the angle of the prism. Should it not strike the first face normal to it, and still be required to emerge from the second deviated through an angle equal to an angle of the prism, it must, when emerging from the second face, fall on that face at an angle of incidence equal to its angle of refraction at the first face, and in its intermediate passage have been reflected at the second and third faces. Hence, these latter two faces must make an angle of half that of the prism. Of the 90° prism, either angle at the base is 45°. Of the second and third prisms, only the angle at the base between the second and third faces is half the prism angles. The angle between the first and third faces, being non-available, is blackened. These partially covered first faces are the ones which must be turned towards the object from which rays are to be deviated by the prisms.

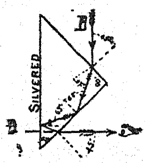


FIG. 10.

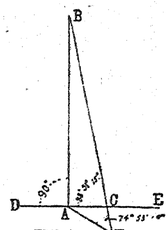


FIG. 6.

A, face towards D at right angles to and to the left of AB. Revolve the ring containing the two prisms until the silvered face of the 90° prism is parallel to the case ring. Turn up the hinges so that the images may be continuous. Hold the instrument with the 90° angle towards the eye (Fig. 7). Notice what well-defined line of B (Fig. 6), seen in the left face of the prism, coincides with a similar line of D, seen directly above or below the prism. Place a stake at A, move backwards aligned on AD, at the same time revolving the prism ring over in the case ring until the edge of the 88° prism is towards the eye and the partially blackened first face is towards B. Stop at the point C where the same coincidence is obtained with this prism as with the first. Measure the distance AC and multiply by 50, the tangent of 88° 51′ 15″, and the product will be the required distance. Should the base be very long, or the ground such as to prevent measuring AC directly, the points A and C having been marked by stakes, the observer moves backward on the line BC until he reaches a point, as F, where, holding the back of the handle towards B and the partially blackened face of the prism towards A, the coincidence is obtained of A in the prism and C seen either above or below. Measure CF and it will be one-fourth of AC or $\frac{1}{200}$ of AB.

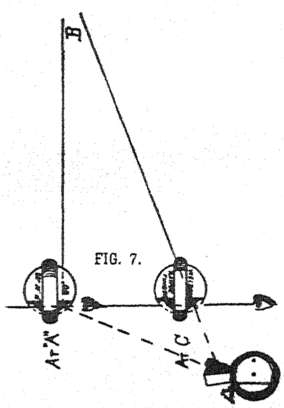
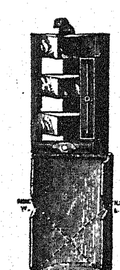


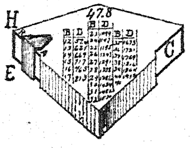
FIG. 7.

When using the Weldon, on revolving it slightly about a vertical axis, some images will be seen to move past very quickly. These must neither be used nor confounded with those that remain steady. They result from surface reflection.

The distance between two inaccessible points may be obtained as with the Pratt.


Weldon Range Finder 1890.

In the improved Weldon, the three prisms are held in a small rectangular lid, having openings between them for sighting through. It has also a small magnetic needle and a spirit-level. The average error of this is said to be only $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent.



SOUCHIER

The Souchier consists of a 5-sided prism of glass, about $\frac{3}{8}$-inch thick, enclosed in a metal case, excepting at the two points C and E, called windows, the latter being provided with a sliding shutter which half closes it. On one face of the cover is engraved a table, giving opposite certain lengths of bases the corresponding distances, and a multiplier to be used for lengths of bases not found in the table. The instrument weighs 1.5 ounces. The principle involved is that of refraction of rays of light passing from air into glass and out again. The angles of the prism are supposed to be, at C, 67° 30′; F, 90°; E, 177° 50′; H, 69° 40′; top, 135°; but they are not always exact; hence the multiplier to be used is given with each instrument. On account of the large angle at E, the angles BC′D and BAD differ by about 1° 10′; hence the multipliers vary between 47 and 52.

To determine a distance AB (Fig. 8). Standing at C′, face the direction point D. Hold the instrument in the left hand between the thumb and first two fingers, all well bent, the prism horizontal, with uncovered window C toward the object B. Place the shutter over the right half (A) of the window E. Looking in the left half (R) of this window, find a line of the image of B by reflection, coinciding with a similar line of some object D seen above or below the prism. This measures the angle DC′B. Place a stake at C′, move backwards, aligned on C′D, until some point as A is reached, where by looking in the right half (A) of the window E, the shutter having been moved over the

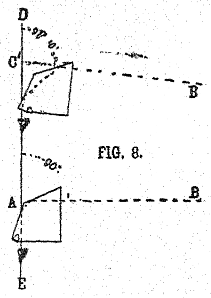


FIG. 8.

left half (R), the coincidence of the same lines of B and D again occurs. This measures the angle DAB. Measure AC′ and look in table for the distance corresponding to it; or, if not found there, multiply it by the multiplier of the instrument, the product being the distance. It may be used for finding the distance between two inaccessible objects.

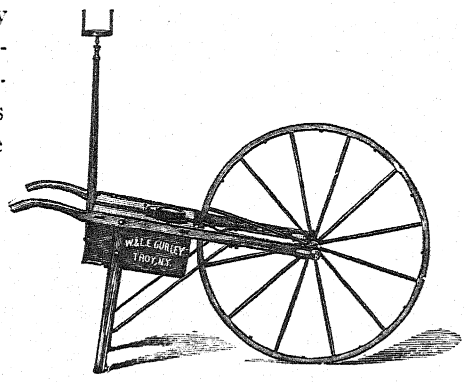
The most serious objection to range-finders like the Pratt, Green, Weldon, and Souchier, requiring bases which bear a fixed ratio to the range, is that for long ranges a long base is required; and that it may happen on arriving at the end of the base, fixed in length and direction, that some intervening object prevents any view of the object whose range is desired. The advantage is in being able to quickly determine the distance between two inaccessible objects, which is peculiarly the property of fixed-angle telemeters.

The great advantage in range-finders like the Gordon, Labbez, and Mekometer is in allowing some latitude in choice of the length or the direction of a base, or both, while in all fixed-angle instruments the base is proportional to the range.

A use to which telemeters may be put is to measure short distances, such as the width of a river, across which to throw a bridge. In military sketching, the taking of offsets from traverse lines can be performed with considerable accuracy with the right-angled prisms or mirrors, and with them one can place himself exactly on the line connecting two distant objects when he is between them. For the latter purpose, on looking into the two faces of the right-angled prism successively the objects and third point should seem to coincide. If they cross, he must advance; if they diverge, he must retire.

THE WHEELBARROW ODOMETER OR PERAMBULATOR is, as its name indicates, an apparatus similar to a wheelbarrow, used for measuring distances when wheeled along a road or path by hand. The wheel is large and light. The number of revolutions is counted by an odometer or otherwise, and, when multiplied by the circumference of the wheel, gives the distance passed over. One form has a box between the handles

for carrying necessary instruments, an upright staff with a vernier pocket compass with a $3\frac{1}{2}$-inch needle for taking bearings, and a positive motion odometer for counting the revolutions of the wheel. All metal work is of brass, so as not to affect the compass.



It is especially adapted to places where wagons can not be taken.

CYCLOMETERS are instruments which record the number of revolutions of a wheel of a bicycle, or give the distance directly.

PEDOMETER.—This is a small instrument, about the size and form of a watch, used for recording the number of steps taken in walking, from which the distance traveled can be computed. By means of a small weighted lever, which descends with every step, motion is communicated to a mechanism composed of a train of wheels, and the number of steps is recorded on a dial by pointers.

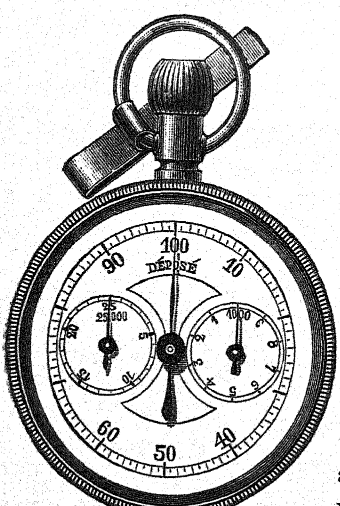
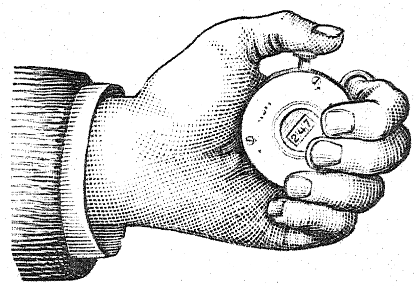


FIGURE 195.

There is another pattern arranged to indicate distances up to 12 miles in $\frac{1}{4}$-mile units, and another up to 50 miles in 80-yard units. The hand advances in proportion to the length of

the step, after being adjusted to this length of step of the bearer by an adjusting-screw.

By the use of an instrument called a Tallying Register (see figure), the record of strides may be kept by the topographer without danger of making mistakes, such as dropping or adding one or more hundreds. Each stride should be recorded as it is taken; after practice, the impulse necessary to make the instrument record becomes almost involuntary.



PACING.—The average length of a person's pace having been determined by walking at an easy, natural, uniform pace over a measured distance a number of times, it can be used for measuring distances to within 2 or 3 per cent of the truth. The average step is about $31\frac{3}{4}$ inches long. The length of the military pace in quick time is 30 inches, in double time 36 inches. On slopes the horizontal projection of the step is usually shorter than the step on level ground, whether one goes up or down hill. One should always take his natural step.

If distances are measured on sloping ground with what is known to be a full-length pace, then deductions must be made to reduce them to corresponding desired horizontal distances. This deduction is about 1 pace from every 250 paces on a 5° slope, 1 pace from every 63 paces on a 10° slope, 1 pace from every 29 paces on a 15° slope, and 1 pace from every 17 paces on a 20° slope.*

A better method, however, would be for one to ascertain the exact horizontal length of his pace by actual trial over measured distances on slopes of different degrees; then by an observation with an instrument or by estimation ascertain the

*As extreme error is only about 3 per cent (the limit to be counted on in ordinary pacing), it is not customary to apply this correction in ordinary small surveys.

degree of the slope to be paced and multiply the number of paces by the length of pace on that slope. Distances of varying lengths over level and sloping ground of varying conditions are measured with a chain or tape and stakes driven at the extremities. An observer passes along one of these lines, having selected before starting an object in prolongation of the line joining the stakes so as to enable him to walk in a straight line, since two direction points are necessary for one to do this. He counts his paces, being careful that they are of the length he would naturally take in walking. Arriving at the other stake, he will record his results with any other observations that may have influenced the length of his pace. He then returns over the same line in the same manner and continues the practice until satisfied with his results. Then he does the same over each of the other lines, until finally he has a record of the length of his paces under all conditions, and can construct scales for any work, or make any necessary corrections.

Care must be taken not to permit the approach to a stake to influence the length of pace, the tendency being to alter it to conform either to the known or estimated distance.

Reliable pacing is limited to slopes not greater than 12° to 15°.

Horse paces. The lengths of a horse's paces at the different gaits can be determined by riding him over measured distances a number of times and taking a mean of the results of the trials. This furnishes a very satisfactory method of measuring distances when sketching mounted, by counting the number of paces* and referring them to a scale of paces constructed from the data so obtained. The length of pace will vary for different horses; hence the necessity for determining it for the horse used, and when done it will be found to be

* In practice it has been found more convenient to count strides, instead of steps or paces—*i e.*, to count the number of times the same foot strikes the ground; hence 1 stride equals 2 paces (or steps), either mounted or on foot.

quite constant. The average of 30 troop horses twice over a measured distance of half a mile, up and down hill, was 965 steps walking, or about 33 inches each, and 680 steps trotting, or about 47 inches each. The U. S. Drill Regulations gives the average step of a horse at a walk as 0.916 yards; at a trot as 1.22 yards.

The U. S. Drill Regulations (Cavalry) gives the maneuver walk at the rate of 4 miles an hour, or 1 mile in 15 minutes, or $117\frac{1}{3}$ yards in one minute. The trot at the rate of 8 miles an hour, or 1 mile in $7\frac{1}{2}$ minutes, or $234\frac{2}{3}$ yards in a minute; the canter at 8 miles per hour; the gallop at 12 miles per hour, or 1 mile in 5 minutes, or 352 yards a minute; the full gallop at 16 miles an hour.

TIME.—Distances are often measured by the time taken to pass over them at a known uniform speed. If sketching on horseback, this method is very useful. Having ascertained the time it takes a horse to pass over a measured distance by a series of trials, scales reading minutes and fractions can be constructed for plotting.

If the sketcher has provided himself with a *stop-watch* which he can fasten on his wrist (see Fig. 208), he can by this means do very satisfactory work, without any of the mental effort required in trying to keep count of paces and without the danger of dropping whole hundreds of paces, which is very commonly done.

SOUND.—Sound travels through the air at a rate of about 1,130 feet per second at a temperature of 70° Fahr. For each degree higher add, lower subtract, $1\frac{1}{7}$ feet. If the wind is blowing in or against the direction the sound travels, its velocity also must be added or subtracted. If the wind blows obliquely, the amount to be added or subtracted will be its velocity into the cosine of the angle it makes with the direction from which the sound comes. Consequently if an observer at one point fires a gun, or makes any other sound, and at the same time a visible signal, and an observer at another point notes the time in seconds (by a stop-watch or otherwise) taken

for the sound to travel, he can approximate very closely to the distance between the observers.

ESTIMATION.—The most inaccurate, yet the most generally used, method of measuring distances for filling in details in hasty sketching is that of estimation by the eye. The art of quite accurately estimating distances can be acquired by careful practice, and it is of the greatest importance to the sketcher, as most distances up to 100 yards are estimated. This is done by a mental comparison with certain known distances, or it may be done on the principle of similar triangles by holding a rule at a certain known distance in front of the eye and seeing how great a space on the rule the object covers; from this its distance may be deduced, provided the size of the object be known.

The degree of approximation attainable after proper practice in the estimation of distances precludes the probability of an error of more than 10 per cent up to 300 yards, of more than $12\frac{1}{2}$ per cent up to 600 yards, of more than $16\frac{2}{3}$ per cent up to 1200 yards.

In determining distances by sight the estimate is based upon the distinctness with which the object can be seen, upon its apparent height when its dimensions are known, and upon a comparison of the extent of the ground between it and the observer with some other known distance which is either within view or so distinctly impressed upon one's memory as to serve accurately as a unit of measure. The distinctness with which any object at any particular distance is visible varies considerably with different men; hence no inflexible rule can be expressed. Actual practice must determine for every individual. As the atmospheric conditions and nature of the background greatly affect the degree of visibility of objects, the practice should be conducted in different varieties of weather and along lines variously situated with reference to the sun and any surrounding hills or woods, particular attention being paid to all these circumstances.

When the light shines directly on objects, or when they are light-colored, or when they are seen against a light background, their details are more clearly visible, and they appear nearer than they really are. So also if the observer's back be towards the sun, or the observation be made in winter when the air is dry and clear, or else just before or after a rain, or if the ground be level and of a uniform tint, or if it rise towards the object, the distance will appear less than it really is.

Under the reverse conditions the distance will appear greater. The tendency in looking from an elevation down to a lower level is to over-estimate the true distance and over-estimate the degree of slope, while in looking upward to a height it is just the reverse. On a wide plain of uniform color, if the eye be arrested by no intermediate points, the estimate will be generally too short.

CHAPTER XVI.

MEASUREMENT OF DIRECTIONS.

In Topographical Sketching the instrument ordinarily used to measure directions is some form of hand compass.

THE BOX COMPASS.—*Description. The rectangular box compass* consists of a circular brass box, from 2 to 3 inches in diameter, containing a needle and graduated circle or card, sunken its depth in a rectangular block of wood from $\frac{1}{2}$ to $\frac{3}{4}$ inches thick, with a hinged cover. To prevent unnecessary wear, a lever and pin are so arranged that the needle is lifted from its pivot whenever the lid is closed.

Or, as more frequently made, a cylindrical hole about $\frac{1}{2}$ inch deep is bored in the block of wood. In the center of this hole is a pivot on which the needle is poised free to move. Around the edge on a plane with the needle is fastened a thin, flat, graduated ring. The usual arrangement for lifting the needle is also provided.

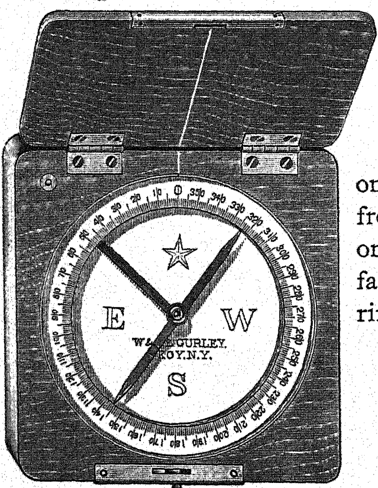


FIGURE 196.

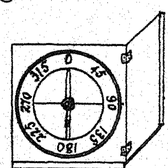


FIG. 197.

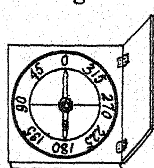


FIG. 198.

The card or ring is graduated into 360°, from 0° to

the right 90°, etc., clockwise (Fig. 197), or from 0° to the left 90°, etc., contra-clockwise (Fig. 198). In one pattern the 0°—180° line is parallel to the hinged edge of the box. An edge of the lid, when raised at right angles to the block, is used for the line of sight. In another (Fig. 196) the line of sight is at right-angles to the hinged edge. A mark on the lid in prolongation of the 0°—180° line being used as the line of sight.

Use. To take a bearing with the first-mentioned pattern, raise the lid at right angles to the box and hold the latter horizontal. The lid being generally hinged on the right-hand side of the 0°—180°, the compass is held in the right hand at several inches in front of the eye. With the zero end of the 0°—180° line directed towards the object, sight along an edge of the lid at the object, watching the oscillations of the needle, which may be checked by pressing on the pin for raising it. The needle must be free, however, at the time of settling. When it has settled, read the north end of the needle. The mean of two or three readings may be taken as the correct one. With the second pattern, hold the compass with the lid towards the object and bring the line on the lid in line with the object and its reflection on the glass over the pivot, then read the north end of the needle. In both these patterns the line of sight and graduated ring both move around the needle, which remains stationary in taking bearings; hence, when figured from 0 at the north to the left (Fig. 198), the readings as given by the north end of the needle are the angles from the magnetic meridian at the north around to east, south, and west. When figured from 0 at the north to the right (Fig. 197), the readings of the north end of the needle are the angles from the magnetic meridian at the north around to the west, south, and east.

THE PRISMATIC COMPASS (Fig. 199).—*Description.* This compass differs from the box compass described, in that the graduated disk or card is fastened on top of the needle with the 0°—180° line coincident with it. The 0 of the disk is usually

placed over the south end of the needle and the 180° division over the north end. On the south end of the box is a sight-vane with a prism which reflects the graduations on the disk up to the eye, while the eye at the same time sees the object observed through a slit in this sight, and the vertical hair in the leaf-sight on the north end. When the leaf-sight is folded down it raises the needle off the pivot. The swing of the needle is checked by pressing on a little button under the leaf-sight which presses a spring against the edge of the disk. On some prismatic compasses there is a mirror on the leaf-sight for reflecting elevated or depressed objects to the eye, and on the prism sight there are colored glasses to be interposed when observing the sun.

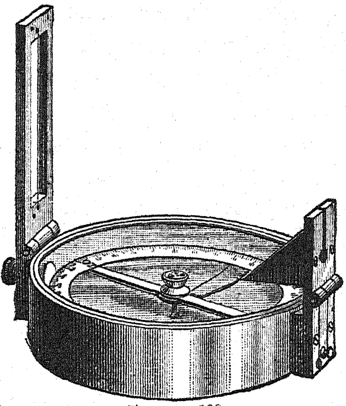


FIGURE 199.

Use. To take a direction with a prismatic compass, turn the prism sight up, slide the prism up or down until the graduations are distinctly seen through it; raise the front-sight; then, holding the prism sight near the eye, sight through the slit above the prism and bring the vertical hair in the leaf sight on the object, and when the needle comes to rest, read the division on the disk which the hair appears to cut. With the prismatic compass, on account of the disk being fastened on top of the needle and remaining stationary while the line of sight revolves around, the graduation of the disk under the eye is read; hence, in order to read zero when sighting north, the 0 of the disk is usually placed over the south end of the needle. If the disk is graduated from 0 clockwise (Fig. 197, page 262), the different readings will be angles from the magnetic meridian to the east, south, west, etc., but if graduated contra-clockwise (Fig. 198, page 262), the readings will be angles from the magnetic meridian to the west, south, east, etc.

Since in both the box and prismatic compasses the disk may, by accident or design, be so shifted that the 0—180° line may have any direction with the line of sight, there is an absolute necessity for always determining the direction of the true north by that compass before using it, in order to place a true meridian upon the plot.

THE PLOTTING DIAGRAM.—*To plot any angle taken with a box compass* graduated from 0° to 360°, the simplest method, requiring no calculation or study, is to first make on a piece of paper a diagram consisting of two straight lines intersecting at right angles. Mark one end of one line 0° and the other end of it 180°; place the box compass on the paper with the line of sight parallel to this line, the eye-end of the line of sight at the 180° end of diagram line. Revolve the paper and compass together until the north end of the needle comes to zero; holding the paper in this position, turn the line of sight to the right through 90° and read the north end of the needle; if this be 270°, which it would be if graduated as in Fig. 197 (p. 262), mark 270° on the end of the line to the right of the 0—180° line, and 90° on the opposite end (Fig. 200); if it reads 90° as when using Fig. 198 (p. 262), *vice versa* (Fig. 201).

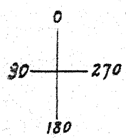


FIG. 200

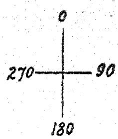


FIG. 201.

With a box compass in which the 0—180° line is parallel to the line of sight, and whose graduations are from 0 at the north around *to the right* (clockwise), then when looking *north*, by a reference to the diagram (Fig. 200) it will be seen that the north end of the needle will read zero; when looking *east*, the needle will read 270°; when looking *south*, 180°; when looking *west*, 90°. If graduated *to the left* (contra-clockwise), then when looking *east* (Fig. 201), the needle will read 90°; when looking *south*, 180°; when looking *west*, 270°. Frequently persons who are left-handed hold the compass in the left hand with the line of sight on the left of the 0—180° line and read the north end of

the needle. By so doing, if graduated to the right, they read: north, 180°; east, 90°; south, 0°; west, 270°. If graduated to the left, they read: north, 180°; east, 270°; south, 0°; west, 90°. But if they construct a diagram as described above, and revolve it 180°, as they have done with the compass, there need be no confusion from this change.

To plot any angle taken with a prismatic compass, the prism or eye-end of the line of sight is placed at the 180° end of the diagram line. The paper and compass are revolved until the 0 of the card comes under the prism. The paper is held in this position and the compass turned to the right through 90° and the number on the card under the prism placed on the end of the line to the right of the 0 of diagram.

With the prismatic compass in which the 0 is over the south end of the needle and the graduations are to the right (clockwise), it will read: *east*, 90°; *south*, 180°; *west*, 270°, as in Fig. 201. If graduated to the left (contra-clockwise), it will read: *east*, 270°; *south*, 180°; *west*, 90°, as in Fig. 200.

If, with either a box or a prismatic compass, a sight be now taken on a true meridian line looking north and the reading of the north end of the needle or number under the prism be plotted from the point of intersection of the diagram lines in the proper quadrant, a glance at the diagram will give the true relations and directions of all lines sighted with that compass. By a reference to this diagram the proper quadrant in which a line with any reading should be plotted is at once seen.

If plotting compass readings is carried on in the field simultaneously with the observations, this diagram and the direction of the true meridian should be put in one corner of the plot, always in sight. The observance of this rule will be the means of preventing many errors.

Plotting compass readings. A protractor may be used in two ways for plotting: *first*, (Figs. 202 and 203), by placing the center on the station point with the diameter along the 0—180° line through it and making a dot opposite the direction of the line on the edge of the protractor, then removing the

protractor and drawing a line from the station through the dot; or, *second* (Figs. 204 and 205), by placing the center on the station and the direction of the line on the edge on the 0—180° line through the station, and drawing a line along the diameter of the protractor from the station for the direction. Which method will be preferred depends upon the compass used, the direction of its graduations, and those of the protractor.

Bx comp grad left Bx com grad right Bx com grad right
Prot grad to right Protr grad to left Prot grad to right

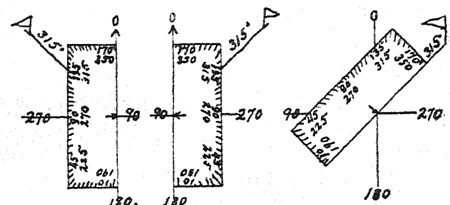


FIG 202 FIG 203 FIG 204

Bx comp grad left:
Protr grad to left

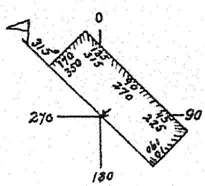


FIG 205

Prism compass and prot grad to right Fig. 202.

Same to left Fig. 203.

Prism compass grad to left and prot. to right Fig 204.

Prismat compass grad to right and protractor to left Fig. 205.

If using a *box* compass, and the protractor is graduated in the *opposite* direction to the compass disk, the *first* method will be the easier; but if the graduations on compass disk and protractor are in the *same* direction, then the *second* method will be the easier in both cases.

In using a *prismatic* compass with disk graduated in the same direction as the protractor, the first method is easier; if the disk and protractor are graduated in opposite directions, the second method is easier.

The *paper* should be prepared for plotting by drawing fine parallel lines about $\frac{1}{4}$ or $\frac{1}{3}$ of an inch apart, to represent the

magnetic meridians to which all the readings refer. One end of these should be marked with a half arrow-head or N before beginning to plot, to avoid making errors.

If the *first method* described above is used, the protractor is laid on the paper with its center at the point from which the line is to be drawn and its diameter edge parallel to the meridian lines, one of which will not be over $\frac{1}{8}$ or $\frac{1}{6}$ of an inch from it. The diagram of the compass readings having been constructed, as described, reference to it at once shows whether the graduated edge of the protractor is to be laid to the right or to the left of the diameter or meridian line, and in which quadrant the line should be drawn.

If the *second method* of protracting is used, then through each station a meridian line is drawn before beginning to protract angles from it, the diagram showing the direction the diameter side of the protractor should take from the station point.

Resection with compass. With a compass one may find the place on a map corresponding to his position on the ground by "resection," when two distant plotted objects are visible. Thus, from the position, take the directions of the two objects, and with the protractor at the plotted position of each object plot their directions and produce them backwards until they intersect; this point will be the place. The accuracy of the resection depends upon securing a good angle at the point of intersection. This operation is useful in finding a convenient starting-point in sketching or for checking the accuracy of a traverse.

CHAPTER XVII.

MEASUREMENT OF SLOPES.

ABNEY LEVEL AND CLINOMETER (Fig. 206).—*Description.* This consists of a line of sight, a level-tube and arm attached, and a graduated arc. The body in which the line of sight is defined is square, so that it may be placed upon a surface and its slope determined by bringing the bubble to

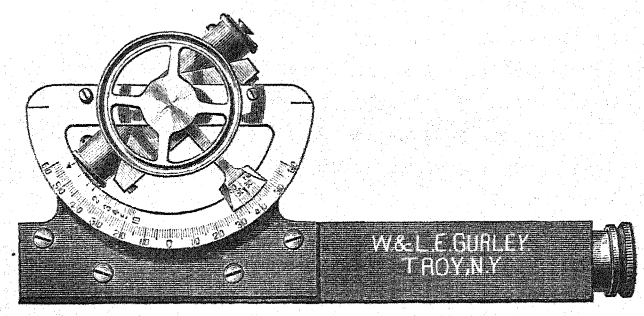


FIGURE 206.

the center of its tube. Directly under the center of the bubble-tube is an opening in the body, and inside, occupying one-half the body, is a mirror facing the eye-end at an angle of 45° with the line of sight. A horizontal wire extends across the middle of the body in front of the mirror. When the instrument is held horizontal and the bubble brought to

the center, on looking through the body the wire appears to bisect the bubble, seen by reflection in the mirror.

Use. When the line of sight is directed upon any object and the bubble brought to the center of its tube, or until the wire bisects its reflected image, the slope of the line of sight may be read on the graduated arc, which is divided to degrees and numbered each way from the zero to 60° or 90°. On the double vernier (Fig. 69, p. 61), on the end of the arm the smallest reading is 10′.

When the vernier is set at zero, the instrument may be used as a hand level to find points at the same elevation as the eye.

The graduations on the inner edge of the limb are the denominators, unity being the numerators of fractions expressing slopes, as $\frac{1}{5}$, $\frac{1}{10}$, etc. The graduation in coincidence with the front edge of the arm is read.

Adjustment: To test for index error. Place the instrument on top of a fence-post, sight to the top of another one several hundred feet distant, bring the bubble to the center, and read the vernier. Go to the other post, sight back, bring bubble to center, and read. One-half the difference of the readings will be the index error to be applied to all readings, being careful to observe whether it is to be added to or subtracted from angles of elevation, and *vice versa.* If the first observation was 2° elevation and the second 3° depression, the index error is $\frac{1}{2}$° to be added to all elevations and subtracted from all depressions.

To make the adjustment. If where it can be done, place it upon a smooth inclined surface, bring the bubble to the center, and read the vernier; reverse it end for end in same place, bring bubble to center again and read vernier. If in adjustment, the two readings will be the same; if not, $\frac{1}{2}$ the difference will be the index error. Apply the index error to one of the readings, set the vernier at that reading, place on the inclined surface, and bring the bubble to the center by the screws at the end of the level-tube. Repeat for a test.

SLOPE BOARD (Fig. 207).—*Description.* A substitute for the clinometer may be arranged on the field drawing board. If one edge is straight, this may be used as the line of sight. On the back of the board construct a graduated semi-circle with its diameter parallel to the line of sight, or paste it on a graduated semi-circular protractor printed or constructed on paper. The graduations should be numbered in degrees each way from the center. Then if a plummet or pendulum be suspended from the center of the diameter, and the line of sight be inclined, the reading of the arc opposite the thread or wire will be the degree of inclination, for the thread retains a vertical position, while the board and attached arc are inclined.

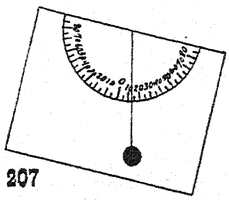


FIG 207

Use. To determine *a slope*, bring the line of sight parallel to it, with the plummet free of the board, then carefully tilt the board until the thread lies on the arc, secure it with the finger, and read off the degrees. To determine *a level line*, with the thread passing through the 0 mark, stick a pin against one side of the thread, then hold the board up until the thread just touches the pin, and sight along the edge. In order to bring the upper edge of the board in line with the slope, it may be necessary to stand back above it until the prolongation of the surface strikes the eye, or to kneel or lie down until the eye is on a level with the grass or some object judged to be at the height of the eye when the slope is taken to it.

CHAPTER XVIII.

CONVENTIONAL SIGNS AND SYMBOLS.

The conventional signs and symbols adopted for representing forms and features on a map are such as to suggest, if possible, the objects for which they stand. Ordinarily no effort will be made to show lights and shadows on military maps, but when they are shown the light is supposed to come from the upper left-hand corner at an angle of 45° with the horizontal.

WITHOUT COLORS.—*Forests* of deciduous trees, except oaks, are represented by signs suggesting irregular projections of trees with bushy tops. In representing oaks, the loops have their points out instead of in as shown.

Perennial trees, as pines, firs, etc., are represented by stars.

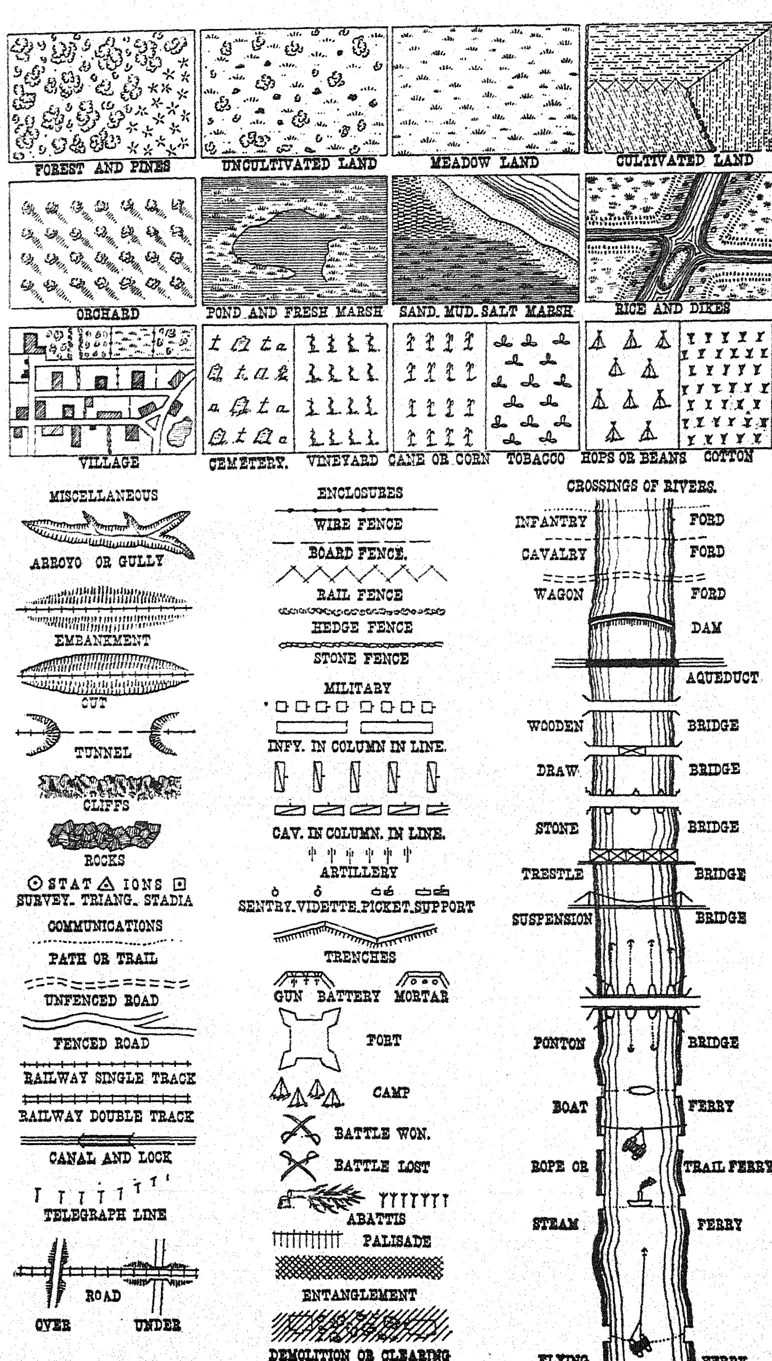
Uncultivated land, which is neither cleared nor forest, is represented by the signs for small trees, grass, and rocks if present.

Meadows or cleared land by signs suggesting tufts of grass, composed of 5 or 7 short lines, the middle one being longest; the bases straight and parallel to the bottom of the map; the tufts evenly but not too thickly distributed and not in lines; dots may be added to produce pleasing appearance.

Cultivated land by signs suggesting furrows, consisting of alternate broken and dotted lines, the breaks short but not opposite each other, the dots fine and close together.

Orchards by regularly distributed trees, sometimes shaded.

Marsh by parallel lines and tufts of grass; if of fresh water, the lines are broken and filled in with the tufts; if of salt water, the lines are continuous and the tufts made over them.


FOREST AND PINES
UNCULTIVATED LAND
MEADOW LAND
CULTIVATED LAND
ORCHARD
POND AND FRESH MARSH
SAND. MUD. SALT MARSH
RICE AND DIKES
VILLAGE
CEMETERY.
VINEYARD
CANE OR CORN
TOBACCO
HOPS OR BEANS
COTTON
MISCELLANEOUS
ARROYO OR GULLY
EMBANKMENT
CUT
TUNNEL
CLIFFS
ROCKS
STAT IONS
SURVEY. TRIANG. STADIA
COMMUNICATIONS
PATH OR TRAIL
UNFENCED ROAD
FENCED ROAD
RAILWAY SINGLE TRACK
RAILWAY DOUBLE TRACK
CANAL AND LOCK
TELEGRAPH LINE
ROAD
OVER
UNDER
ENCLOSURES
WIRE FENCE
BOARD FENCE.
RAIL FENCE
HEDGE FENCE
STONE FENCE
MILITARY
INFY. IN COLUMN IN LINE.
CAV. IN COLUMN. IN LINE.
ARTILLERY
SENTRY. VIDETTE. PICKET. SUPPORT
TRENCHES
GUN BATTERY MORTAR
FORT
CAMP
BATTLE WON.
BATTLE LOST
ABATTIS
PALISADE
ENTANGLEMENT
DEMOLITION OR CLEARING
CROSSINGS OF RIVERS.
INFANTRY FORD
CAVALRY FORD
WAGON FORD
DAM
AQUEDUCT
WOODEN BRIDGE
DRAW BRIDGE
STONE BRIDGE
TRESTLE BRIDGE
SUSPENSION BRIDGE
PONTON BRIDGE
BOAT FERRY
ROPE OR TRAIL FERRY
STEAM FERRY
FLYING FERRY

Ponds by equidistant lines parallel to the bottom of the map, suggesting still water.

Streams and large bodies of water by lines suggesting waves along the shore. The high- and low-water levels by distinct shore-lines. If streams are not large enough to be water-lined, they are represented by a full sinuous line.

Dry runs by dashes and three dots between.

Sand and *gravel* by dots.

Mud by short dashes.

Buildings on small scales are usually shown as rectangular blocks; on large scales, by the shape of the building in outline, and filled with fine diagonal lines, the outline for wooden buildings being very fine, for brick heavy, and for stone very heavy.

Streets of towns and villages should be shown as they are.

Crops. Although signs are often employed to represent different crops, features, etc., it is not safe to trust their doing so without the name attached. Their employment is more for pictorial effect than otherwise.

Arroyos or gullies have their outlines sharply marked, and hatching lines are added to represent the slopes or wash of the earth.

Embankments or fills have the highest outlines sharply marked and hatching lines for the slopes or fall of earth.

Cuts have the cutting or highest line sharply marked and hatching lines for the slopes. The cuts up to the mouth of tunnels are shown. The tunnel itself is shown by broken lines.

WITH COLORS.*—The use of colors on hastily executed military maps will ordinarily be limited to a very few in number (four or five), and they will be applied with colored pencils which can be carried in the field. The forms of the various conventional signs are similar to those already described.

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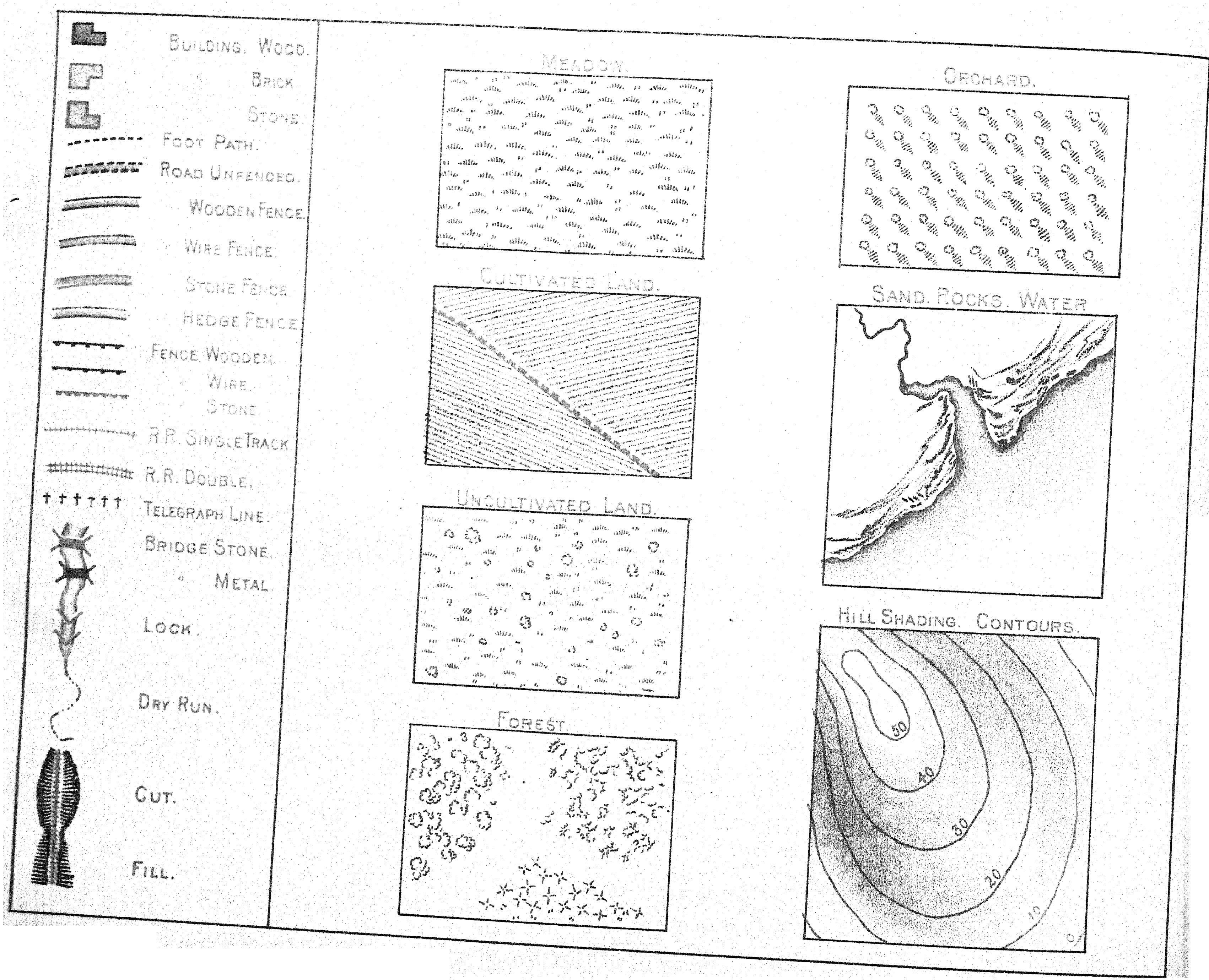
*For a complete description of the use of water-colors on maps, and how to apply them, the student is referred to "Topographical Drawing and Sketching," by 1st Lieut. Henry A. Reed, U. S. A.


Building, Wood.
" Brick.
" Stone.
Foot Path.
Road Unfenced.
Wooden Fence.
Wire Fence.
Stone Fence.
Hedge Fence.
Fence Wooden.
" Wire.
" Stone.
R.R. Single Track.
R.R. Double.
Telegraph Line.
Bridge Stone.
" Metal.
Lock.
Dry Run.
Cut.
Fill.
Meadow.
Orchard.
Cultivated Land.
Sand. Rocks. Water.
Uncultivated Land.
Hill Shading. Contours.
Forest.
50
40
30
20
10
0

Wooden buildings, fences, telegraph poles, etc., are drawn in *brown*.

Brick buildings with a *light red border*, stone buildings with a *heavy red border*, all filled with a *light flat tint of red*.

Masonry bridges, stone fences, railroads, etc., in *red*.

Wire fences, metal bridges, and water in *blue*.

Dry runs by broken and triple-dotted *blue* lines.

Earth and sand in *yellow ochre*.

Cultivated land ruled with *brown*, over a flat tint of *yellow ochre*.

Trees, grass, and vegetation in *green*.

Rocks in *brown*.

Contours in *red* continuous lines of constant thickness, except every fifth, which is sometimes made heavier.

Lettering is usually done in *red*.

HILL SHADING.—A method much used in the past for shading hills was by short strokes, called *hachures*, drawn either perpendicular or parallel to the steepest slope, the thickness and number of which were regulated by a *scale of shade* according to the degree of slope, the steepest being darkest. As it has the effect of covering up details and was difficult to properly produce, it is being superseded by *lead shading*, which is more easily and rapidly executed and does not destroy details.

In *lead shading* the object is to produce a *transparent shade*, darkest where the ground is steepest. Its purpose is to give body and expression to the map. In this, rays of light are supposed to be vertical; hence horizontal surfaces are lightest or white. On slopes, the rays striking obliquely, the illumination is less bright, decreasing with the increase of the slope, being least for angles of 35° or upwards; hence slopes are shaded, the shade being denser as the slope is steeper.

How produced. Lead dust from a soft pencil is scraped on a piece of paper, lumps being carefully avoided. The map is placed on a smooth hard surface. With a piece of chamois skin folded into a firm point some of the lead is taken up and applied to the map by sweeping movements in the direction

of contours, endeavoring to produce broadly the desired effect as regards depth of shade, the first application of lead being on the portions to be the darkest, representing the steepest slopes, fading away to the lighter portions. Care must be taken to avoid hill-tops and parts which are to remain light.

When the broad or general effect of shade has been produced, a fresh point is folded and the map rubbed with it, forcing the lead into the grain of the paper, blending the different shades and removing any mottled appearance; a fresh point is again folded, the blending continued, and so on until the desired effect is produced. Some portions, where very steep, may now require to be again darkened with more lead and other portions brightened with a pencil eraser and again blended. Very dark shades cannot be rubbed too hard without removing too much of the lead. The shading of abrupt rocky cliffs, etc., may be finished with a pencil. To bring out a small portion of high light; a hole of the required shape is cut in a piece of paper, held over the place, and the lead removed with an eraser.

Exaggerating the contrast of light and shade to produce *relief* at the expense of truth is to be avoided. Water-sheds may, however, be a little lighter than contiguous water-courses. Colors should be applied after the shading. The shading which has been unavoidably carried beyond the border can be removed by placing a piece of paper with the edge on the dividing line and using an eraser.

Lead shading may be fixed with a spray of gum arabic water.

CHAPTER XIX.

FINISHING MAPS.

LETTERING.—The final appearance of a well-drawn map may be anything but pleasing, as a result of poor or unsuitable lettering. The letters should be simple, neat, and of a size proportioned to the scale of the map, their position, and the objects to which they refer. Fancy letters are out of place and script should never be employed. When lettering on a map or sketch will not obscure valuable details, it is to be preferred to reference numbers, which are sometimes necessary, however, in conjunction with marginal notes or a separate report.

Styles used. The letters which are most useful are the **GOTHIC,** ROMAN CAPITALS, Roman lower-case, *ITALIC CAPITALS, Italic lower-case.* A very common style of lettering maps and other drawings is styled "Round Writing," in which all lines are made with a stub pen thus:

A B C D E F G H I J K L M N O P Q
R S T U V W X Y Z.

a b c d e f g h i j k l m n o p q r s t u v w
x y z. 1 2 3 4 5 6 7 8 9 0.

Another style, known as the "Marking Alphabet," is very easily and quickly acquired.

Marking Alphabet.

ABCDEFGHIJKLMN
OPQRSTUVWXYZ&
abcdefghijklmnopqrst
uvwxyz.

When done. As a rule, lettering is done after the features have been drawn, but in pen drawing, large bodies of water, forests, etc., are lettered before the signs are drawn, to avoid blurring. In general, the lettering is parallel to the bottom of the map, but rivers, roads, etc., are lettered in the direction of their courses and so as to be most easily read.

The title. This is usually placed within the border in one of the corners of the map. The middle points of all the lines should be in a vertical line. The name of the locality is generally the most important and most prominent word, but should not exceed in height $\frac{1}{30}$ the length of the short side of the border. The letters of the other words may vary in size according to the importance of the words.

The name of the draftsman, date of the survey, and like information, appear in small letters.

The scales. Below the title or in some other convenient place should be drawn a graphical scale of distances, with a legend of "So many inches to the mile," etc., and, if desired, the representative fraction. In a contoured map a statement of the vertical interval between contours and a graphical scale of horizontal equivalents is added.

The meridian line or needle several inches long must always be drawn, as it determines the relative directions of all

objects represented. When the survey has been made with a compass, the *magnetic meridian* is drawn, and also the *true meridian* if the declination of the compass is known. These should be two lines intersecting near their middle, making an angle with each other equal to the declination. The true meridian is drawn with a full arrow-head, and the magnetic meridian with a half arrow-head on the side of the declination. When the map is colored, it is well to make the arrow-head red to draw attention to it. The needle should be assigned a prominent place on the map.

The border. The map is generally arranged so as to be enclosed by a rectangle, the sides being in north-and-south and east-and-west directions, with the top of the map towards the north, whenever practicable. The border generaly consists of two lines, the interior one light, the exterior one $\frac{1}{200}$ of the small side of the rectangle in width, with an equal space between the lines. The heavy outer line may be filled in with a brush or shading pen.

CHAPTER XX.

MAP-READING.

Map-Reading is the art of grasping quickly the correct meaning of a military or other map, and is only acquired by a careful study of the principles of topography and the ground, thus developing a just appreciation of the relative heights of hills, the steepness of slopes, and the shapes of features as shown by the contours and other symbols.

Every officer should be thoroughly competent to make use of maps both for strategical and tactical purposes, and should possess a good eye for ground, one of the greatest gifts, from a military point of view, a soldier can possess. He should be able, with the aid of a map, to move to any place pointed out, and to occupy it in any manner ordered. It is impossible for any soldier to discuss the simplest problem in connection with tactics or field fortifications without taking into full consideration the topographic aspect of the case, and having recourse to maps; hence the ability to read a map readily and to make use of it intelligently is one of prime importance to an officer.

AIDS IN MAP-READING.—*A thorough acquaintance with the conventional signs and symbols* is necessary, as well as the *ability to appreciate distances to scale.*

As an aid to learning map-reading, one may take a map of a piece of ground to some commanding spot on it, and there study how to identify his position on it, how to recognize the different forms and features, as water-sheds, water-courses, cols, etc., and how the contours curve for the different shapes and slopes they represent. To do this, it is first necessary to note the scale of the map, and to impress on the

mind the spaces on the map corresponding to certain distances on the ground.

Orienting a map on the ground. The map is spread out, and, if possible, fastened to a drawing-board or box lid, and then oriented.

This may be easily done as in orienting the plane table if one has a *magnetic compass* and the map has a magnetic meridian on it. If the map has a true meridian and the declination of the compass is known, a magnetic meridian can be drawn.

If no compass is at hand, and the exact spot occupied is not located on the map, it may be found by the *mechanical method* previously described; and then, if any distant conspicuous point or object can be identified on the map, it can be oriented by placing the edge of a ruler on the plotted points of the position occupied and the distant object, and the whole map turned until the distant object is sighted. By now pivoting the ruler on the plotted position of the point occupied, objects may be sighted, their distances estimated, and their plotted positions recognized.

Finding one's place on the map. If the map is oriented by the compass, but the position occupied is not plotted, it can be found by resection on two known plotted points that can be recognized.

One of the difficulties in making use of maps is, that they may not be corrected up to date, and time may be lost in trying to find roads that have ceased to exist, or in searching in vain for important buildings, railways, etc., that have been built since the map was drawn.

READING MAPS.—To read a map, first look to the *lie* and *direction* of the streams; note how the *water-courses are generally found to trend*, as this will indicate the lowest levels; next observe where the *features of ground project towards the streams*, as this shows the positions of water-sheds and spurs; *where they recede* shows the valleys.

If the heights of the contours are indicated, showing elevations above some datum plane, there can be no mistak-

ing hills for hollows; the relative heights of different points are found by the differences of the numbers of the contours on which the points lie.

If the contours are not numbered, then the existence of water must be one's guide in distinguishing between water-sheds and water-courses. The lowest part of a country is usually occupied by the largest body of running water. From this the tributary streams may be traced upwards to their sources, thus locating the valleys, in which the contours curve outward from the main stream. The water-sheds lying between the valleys may next be distinguished by the contours curving towards the main stream. Having found the water-sheds, next locate cols or saddles connecting the different features. If the contours are not numbered and the points whose relative heights are desired lie on adjacent features, count the number of *contour intervals* to each of them, either from the col which connects the features, or the water-course which separates them, and multiply their difference by the interval between the contours. As *contour intervals are counted* and not contours, the first, or lowest, contour at the col or water-course, where the counting begins, must be considered as 0 and not 1.

SECTIONS.—One test of the understanding of map-reading is the ability to make *sections* of the ground on any required line. In fact, the studying of a map largely consists in mentally making sections along different lines.

A section is the representation of the intersection of the surface of the ground by a vertical plane. If one imagines the surface to be cut by a vertical plane, and the rest of the ground nearest him to be removed, the result would be to expose a certain irregular profile, which is represented in the construction of sections (Figures 191, 192, 193).

The horizontal distances are generally made on the same scale as the map, while the heights are usually exaggerated a number of times in order to show more strikingly the changes of slope which, in a true section, would be barely perceptible

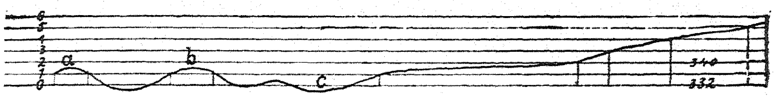


FIG. 191. SECTION thro' hills 336 and 452 north. Heights to Distances as 15 to 1.

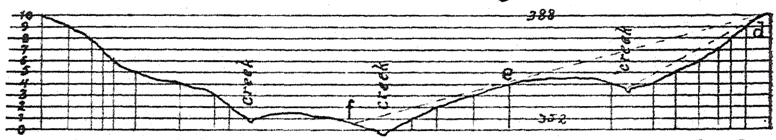


FIG. 192. SECTION from J. CRAWFORD to hill 388 east. Hgts to Dsts as 15 to 1.

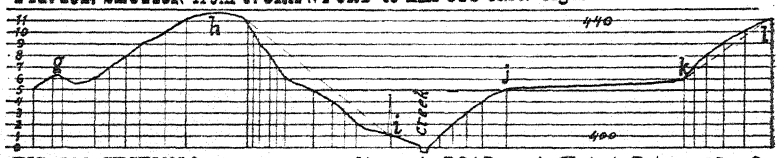


FIG. 193. SECTION from s. w. corner of town to ROAD west. Hgts to Dsts as 15 to 1.

on the scale of the map. The exaggeration of the vertical to the horizontal scale should always be stated under the section as "Heights to Distances as 5 to 1," or whatever it may be.

To draw a section on a given line of a contoured map.

1st method: Lay a straight-edged piece of paper along the section line and dot along the edge the exact points where the line cuts the contours, and also any intermediate point where the slope changes, as on water-sheds and in water-courses. Number these points 0, 1, 2, 3, etc., corresponding to the relative height of the contour of each, calling the lowest contour 0, or number them with the heights above datum. Care must be taken that every time the same contour is cut by the section line the dots are numbered the same.

Now draw lines parallel to each other, at a distance apart equal to the vertical interval between the contours to the exaggerated scale, to represent the contour planes, and number these from the bottom up 0, 1, 2, 3, etc., or beginning with the lowest contour height, corresponding with numbers of the dots. Place the edge of the piece of paper which was laid on the section line along the bottom line and dot off the points marked thereon, and from each of these points raise perpendiculars to

the parallel line having the same number as the point from which each is drawn; then join the tops of the perpendiculars.

2d method: For purposes of map-reading, a simpler method may be employed. On a strip of paper a little longer than the section to be drawn and 3 or 4 inches wide, draw lines parallel to the long edge at equal distances of about $\frac{1}{8}$ or $\frac{1}{10}$ of an inch, and other lines at the same distance apart perpendicular to these. Place the edge of the paper on the section line, and from each of the points of intersection with the contours draw a vertical line till the horizontal line which represents the level of the contour is reached; then join these points.

ELEVATIONS.—*An elevation* of the ground shown by contours is the representation of an orthographic projection of it on a vertical section plane. The observer's eye is always supposed to be exactly at the same level as the spot observed and looking at it perpendicularly to the section plane. The section occupies the foreground; points behind the plane higher than the section will appear above it, and those on the same level and lower will be hidden. The outlines of the hills nearest the front will first be drawn after the section, then the other outlines in succession backwards. Any details, as roads, houses, etc., which would be visible, may also be shown in their proper positions in the elevations (Fig. 194). The locations of the various points are found by drawing from them lines perpendicular to the section plane until they inter-

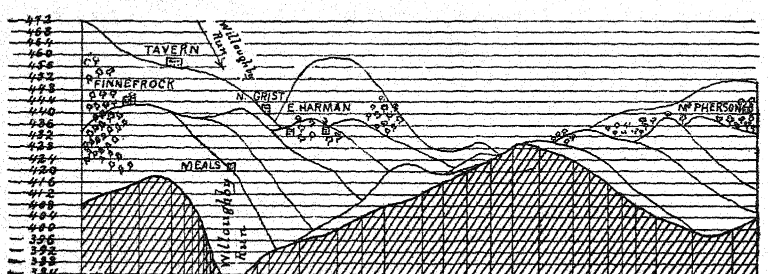


FIG. 194. SECTION on s. w. edge of map and ELEVATION north. Hg to Ds as 15 to 1.

sect the horizontals whose numbers correspond to the heights of the points.

PROBLEMS.—Map-reading includes the following problems:

Determining the direction of the flow of streams.

Determining the location of water-courses, water-sheds, and cols.

Numbering the contours.

Determining the visibility of one point from another.

Determining the horizon visible from a given point.

Determining where a given line pierces the ground.

Calculating the height of a point just visible from another point, etc.

In this determination the height of the observer is not taken into account, as undulations may occur between contours and not be shown, while walls, fences, brushwood, etc., may also intervene.

To determine the various features.

Problem 1: Place arrow-head on meridian line of Gettysburg map, near marsh. Place arrow on all streams, showing direction of flow. Number all contours and hill-tops. Trace all contours whose references are divisible by 20, in red. Construct scale of distance to read feet, also scale of horizontal equivalents.

To determine the visibility of one point from another.

Problem 2: Let it be required to determine whether *i* (Fig. 193) is visible from *h*. From the section drawn on this line it will be seen that the points are mutually visible, because all of the ground between them lies below the broken line *hi*, and the general section is concave. This same fact can be recognized from the contours, without drawing a section, because they are closer together at the top of the slope than at the bottom. If the ground had the shape shown between *k* and *l*, neither point would be visible from the other, because the ground passes above the broken line *lk*, and the general section is convex, which fact can be told from the contours lying closer together at the bottom of the slope than at the top.

Hence the visibility of one point from another depends upon the general concavity or convexity of the section of ground between the points, which can always be determined by drawing a section, but there are simpler processes of arriving at the same results. The only difficulty in this is to determine *what point*, if any, may intercept the view. Thus, between *k* and *i*, the first part of the section may be gentle, as between *k* and *j*, the intercepting point being *j*, where the slope becomes steeper; or some knoll, spur, or water-shed may intervene, as *h* between *g* and *i*. The slope of the ground between the observer and intercepting point, as the slope *lkjih*, does not affect the visibility of points beyond, as *g*, but the degree of slope of *hg* beyond the intercepting point *h* as compared with the slope *hl* of the right line joining the first two points does affect the visibility. If the intercepting point *b* (Fig. 191) is at the level of the observer at *a*, no lower point *c* beyond is visible.

Since a section across a ridge is convex, points on opposite sides, as *g* and *i*, are invisible. A section across a valley is concave; hence points on opposite sides are generally visible, as *h* and *j*, the exception being when the first part is very gentle, as *kj*, and grows steeper to the water-course, as from *j* to *i*.

Problem 3: Referring to the map: Is the stream, where the fence crosses it near H. McDonald's, visible from the road from Gettysburg where same fence meets it? By an inspection of the map it is seen that the section is convex and the stream invisible, the intercepting point being where the fence crosses contour 428 just north of hill 432. For, from the road to this point is a slope of nearly 3 contour intervals in 0.6 of an inch, while from this point to the stream is a slope of nearly 7 intervals in 0.8 of an inch; hence the slope from the intercepting point to the stream is steeper than the line from the road to the intercepting point, and the stream is invisible.

Problem 4: Is the letter S on the meridian line visible from hill 460 west of Seminary Ridge? The contours being

close together at top and separating towards S, the ground is concave and S is visible, there being no intercepting point.

Problem 5: Was Hagy's visible to Wilkinson's Battery on hill 404 northwest of Thomas Scott's? By drawing a line from hill 404 to Hagy (house nearest H) it is seen that hill 400 may intercept the view. It is one contour lower in about 2 inches, while the house is one contour lower than hill 400 in about $1\frac{1}{2}$ inches; hence invisible.

Problem 6: Were Davis' Mississippi troops crossing the bridge over Willoughby Run north of Spangler's visible to the 20th New York troops on hill 432 west of E. Harman's? The hill north of 432 may intercept the view. This is 3 contours lower in about $1\frac{1}{2}$ inches, while the bridge is 4 contours lower than the intercepting hill in about 3 inches; hence the bridge is not hidden by this hill-top.

Another method is as follows: Since the intercepting hill is 3 contours lower than the point of observation, $\frac{1}{3}$ of the horizontal distance between them will be the horizontal equivalent for 1 contour interval of the right line joining them. If this horizontal equivalent be now applied on the line to the bridge from the intercepting point, as many times as there are contour intervals between it and the bridge, and the last application does not reach the bridge, it shows the latter is not hidden by the hill-top. If the last application extends beyond the bridge, it would be hidden by the hill-top.

To find the point where a line of given slope from a given point pierces the ground.

Problem 7: Find the point of piercing the ground of the right line just touching the hill 460 in woods on Seminary Ridge and the hill 452 due west. The line has a slope to the west of 2 contours between the hills, a distance of 1.1 inches. The horizontal equivalent of 1 contour interval will be .55 inch. Beginning at the western hill, lay off this distance and compare each time with height of ground. The end of first length is 448 in height and is over contour 440, so is above ground; in the second length it pierces hill 448, the end 444

being over 440 contour; the third length 440 is over 432; the fourth length 436 is over 404; the fifth length 432 is over 408 west of Willoughby Run; the sixth length 428 is over 422; the seventh length 424 is under 432, hence it must have pierced the ground somewhere; $\frac{1}{2}$ its length, being 426, reaches midway between the contours 424 and 428, hence here is where it pierces.

So the point where any line pierces the ground, starting from a given point with a given slope, can be determined.

To find the visible horizon from a point is to determine the line separating all the visible from the invisible portions of the ground with regard to that point. To do this a number of radiating lines are drawn from the point of observation and along these the portions of ground which are visible are determined by the methods explained above. The points determined as separating the visible and invisible are then joined, forming the horizon, which if the map were large enough would be a closed line perhaps with loops.

In a limited portion of a country it is evident that there may be several visible horizons.

Problem 8: What was the visible horizon of Lane's 7th N. C. at 4 P. M., when in depression on south edge of map $2\frac{1}{2}$ inches east of Willoughby Run, height 400? By drawing radiating lines and determining what portions of them are over seen and what over unseen ground, the horizon will be found to run irregularly along the ridge through the word Hagerstown almost up to the hill 480 east of J. Forney's, then back again along Seminary Ridge.

Problem 9: If the horizon is to be determined from a high hill, as Benner's Hill, height 452, the problem becomes more complicated. A point of Seminary Ridge south of Q. McMillan's is just visible, McMillan's being hidden by the ridge west of East Cemetery Hill, the south part of which is hidden by ridge of East Cemetery Hill; the line down the latter extends to contour 428, when it divides: one part going west to the creek, crosses, then tends southwest up the slope to ridge

at about 448, down ridge, across col, over hill in town, down ridge towards Stevens' Run; another part winds off from 428 around to the southeast, off the map, on again, down the ridge to 408, across Rock Creek, etc. There are other portions.

To calculate the height of a point just visible.

Problem 10: An object at i (Fig. 193) is just visible from k, over the point j; what is the height of the object? The distance of j from k is 928 feet and its fall 1 contour (4 feet). The distance of i from k is 1,533 feet; hence by similar triangles its fall is $928:1533::4:x=66$ feet; but i is 5 contours or 20 feet below k, while the top of the object is only 6.6 feet below k; hence the object is $20-6.6=13.4$ feet high. Or, since the slope of the line from k to j is 4 on 928, or 1 on 232, then the fall from j to the object on this line will be as many feet as 232 is contained times in $605=2.6$ feet. Now i being 4 contours or 16 feet below j, and the top of the object 2.6 feet below j, the object must be $16-2.6=13.4$ feet high.

Problem 11: The ridge of a house in Gettysburg on the 3d contour below the number 412 is just visible from contour 480 of East Cemetery Ridge; how high is the house? The intervening hill is distant 2,300 feet from the observer and 36 feet lower; the house is 2,860 feet distant; hence by similar triangles $2300:2860::36:x=44.8$ feet lower than the observer. But the contour on which the house stands (420) is 60 feet lower; therefore the house is $60-44.8=15.2$ feet high.

Problem 12: Where and what is the steepest gradient on the Hagerstown road? Applying the scale of horizontal equivalents it is found on the east slope of Seminary Ridge and just west of Willoughby Run, about 7.5 degrees or 1 on about 7.6.

CHAPTER XXI.

COPYING MAPS.

COPYING SAME SIZE.—Maps may be copied the same size—

1st. By fastening a piece of tracing-paper or tracing linen on the map and tracing over the lines with a pencil, or with pen and ink. If tracing-linen is used, the lines are drawn on the glazed side, and if to be tinted, the colors are applied on the back.

2d. By fastening the drawing-paper on the map and holding both against a window, or a pane of glass in a frame, so situated as to receive a strong light on the back; then trace the lines.

3d. By *transfer paper* as previously described.

4th. By dividing the map to be copied into a certain number of equal squares or rectangles, with sides from $\frac{1}{2}$ inch to 2 inches, depending upon the amount of detail to be copied and the accuracy required. The paper on which the copy is to be made is then divided into squares or rectangles of the same size, which are numbered the same on both.

The points where the different prominent lines on the map, as roads, rivers, etc., intersect the sides of the different squares are marked on the corresponding squares on the paper to contain the copy and then properly joined. These being drawn in, the other details are "sketched in" in their proper positions. For greater accuracy within the squares, points may be located by perpendiculars from the sides, or by the intersection of arcs from two corners of the square.

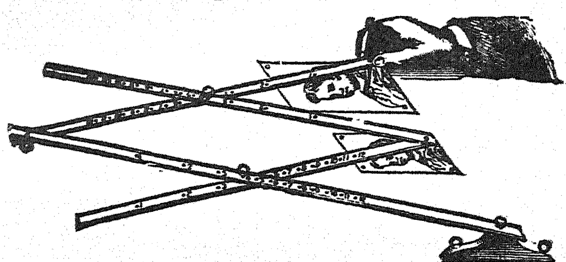
In copying contours, draw on the map lines of greatest slope on water-sheds and in water-courses; draw these on the

copy, marking on them where the contours cut, and then join them with the proper curves.

Instead of defacing the map by drawing the squares on it, a pane of glass with the proper size squares ruled on it, or a frame with a fine silk thread stretched from side to side forming the proper size squares, can be laid on the map.

5th. By photography in the regular way, or by making the map translucent with oil or otherwise, then placing the printed side next the sensitive side of a plate and exposing to light, etc., thus obtaining a negative from which any number of copies may be made in a variety of ways.

6th. By using the pantograph. This is an instrument



consisting of four pieces of wood about $\frac{1}{8}$-inch thick, $\frac{3}{4}$-inch wide, and from 18 to 36 inches long, fastened together with movable joints so as to always form a parallelogram. To use it, a tracing-point is make to travel over the outlines of the map; a pencil is so connected with the tracing-point that it is always in a straight line with the tracing-point and with a fixed center, and always at a distance from that center bearing a given constant ratio to the distance of the tracing-point from the center; the pencil draws the outlines of a copy of the map in the given ratio.

REDUCING AND ENLARGING MAPS.—Maps may be enlarged or reduced by photography, or with the pantograph, but the only method usually available for officers is by means of squares or rectangles. The original will be divided as explained, and the paper to contain the copy will be prepared with the same number of squares or rectangles having sides

bearing the required ratio to those of the original. The details are then copied to the enlarged or reduced scale.

The distinction must be thoroughly understood between enlarging to two, three, or any other times the size (area), and to two, three, or any other times the scale. Likewise for reductions. Thus a map 6 inches square containing 36 square inches enlarged to *two times the size or area* will contain 72 square inches and will be 8.485 inches square; while the same map enlarged to *two times the scale* will contain 144 square inches and be 12 inches square.*

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* In enlargements in terms of size or area, the relation of the sides is found as follows: n inches on the map will be represented on the copy double the size by $n\sqrt{2}$, and on the copy three times the size by $n\sqrt{3}$, etc. In reductions, n inches on the map will be represented on the copy one-half the size by $\sqrt{\frac{n}{2}}$, and on the copy one-third the size by $\sqrt{\frac{n}{3}}$, etc.

CHAPTER XXII.

METHODS OF FIELD WORK.

GENERAL IDEA.—Before beginning the actual work of sketching a piece of ground it will be an advantage to proceed to some elevated portion of it, from which a good view can be had, and there obtain a general idea of the shape of the forms and features, and a good mental picture of the appearance they will present in plan.

BASE-LINE.—Some convenient piece of level ground without obstructions is next selected, over which is measured, or paced, several hundred yards for a base line, from the extremities of which the principal objects on the ground can be seen.

INTERSECTIONS.—Then from both ends of this base-line the directions of all the prominent objects on the ground to be sketched are taken with the compass; if using the plane table, their positions are fixed by intersection. These objects may be spires of churches, chimneys of houses, a flag-staff, gate-post, isolated trees, etc., all of which, when correctly determined, serve as stations from which to start to fill in the details.

TRAVERSING.—Having completed this, the next operation is *traversing* the roads and other lines and sketching in the details, such as houses, fences, streams, bridges, woods, railroads, etc.

Traversing should be performed with as few changes of direction as possible. Thus, instead of following the center of a winding road by a number of short courses, it should be traversed from side to side with as few and as long lines as possible, the directions being taken on the most distant points visible from each station.

In traversing across undulating ground, one is liable, on descending into hollows, to lose sight of the point towards which he is pacing. Foreseeing this, he should look for some object, as a bunch of grass, bush, or other mark, on the alignment, so situated that it will remain in view at such times, thus preserving the direction of the course. When a traverse line crosses a stream, cutting, or anything narrow that interferes with measurement, the distance to the further side should be estimated and the pacing resumed there.

Obstacles, such as ponds, houses, etc., situated on the traverse line may be passed by triangular or rectangular offsets as already described.

When "filling in" the details of ground on which stations have been fixed by triangulation, intersection, or otherwise, the traverse generally commences at one of these stations and is carried up to and "closed" on another as soon as possible. If there is a large error in closing, it is best to traverse back from the closing station, by which the error may be discovered and corrected. If the error of closure is not large, it may be distributed among the last few courses. The traverse may then be started anew and carried forward to another station. The scale at which the notes are to be plotted must be constantly borne in mind, and the notes not burdened with offsets and objects too small and unimportant to be represented.

The forward measurements are commenced anew at each station, but all intermediate measurements are inclusive from the back station.

The *principal rule* to bear in mind in arranging the work is to make the operations as large as possible, using only long traverse lines and long offsets, in preference to changing the directions frequently to sketch in details.

Secondary offsets, perpendicular to the principal offsets, may have to be made in order to sketch in some details.

It is by means of offsets from traverse lines that most of the details of the ground are filled in. Thus, to locate a stream or irregular fence, the direction of a course close to and

parallel to its general direction is observed, and perpendicular offsets are measured or estimated to the points which best define its forms. To sketch in a winding road through a field, traverse a line parallel to its general direction and determine its sinuosities by offsets.

To sketch in a winding road or stream which *cannot be traversed*, draw the direction to some distant point of it, then estimate the forward distances along this line to the successive points where offsets would be taken, if traversing along this direction line, and then estimate the lengths of the imaginary offsets at the successive points and plot them in.

Offsets to two points of a straight line, as a railroad, fix its position with reference to the traverse line.

Offset measurements are all inclusive from the traverse line, and not from one object to another, if they happen to be on the same offset line.

Before leaving the traverse line to pace or measure an offset, a mark should be left at the spot, so that the forward measurements may be resumed there.

The notes should include as much of the country as can be well examined on each side of the traverse line, depending somewhat on the scale and the time available. But nothing will be recorded nor sketched that is not seen or at least known.

traverse, and determining the positions of adjacent objects with reference to these lines; the measurements and observations being entered in the Field Note Book, from which the plan is subsequently plotted.

Description of book. The Engineer Department Topographic Field Note Book, specimen pages of which are shown in plates "a" and "b," is a book 8½x12 inches when open; on each left-hand page are ruled five columns, from top to bottom; the center one, $\frac{9}{10}$ inch wide, marked "Courses and Distances," is used for recording only the forward directions of the traverse lines and the forward distances along these lines. On each side of the center column is one, ½ inch wide, in which are recorded the offsets or perpendicular distances of objects from the traverse line. The marginal columns, nearly 2 inches wide, are for remarks. The right-hand pages, which are used for sketching as the traverse proceeds, are ruled into square inches, have a blank protractor printed in the center, and scales of 8ths and 10ths of inches at the bottom.

Recording. The note-book, in traversing and sketching, should be so held that the *top will always be in the forward direction* of the traverse line, thus having the book approximately oriented, and care should be taken that objects to the right and left are recorded in their respective "Offsets" columns and sketched on the proper side of the drawn traverse line. All records and sketching will begin at the bottom of the page and be carried up to the top.

The notes should be of such character as to be readily understood and plotted by another. The figures should be legibly printed and the entries should not be crowded.

To avoid confusion and mistakes, all figures should be marked, as yards, paces, etc., if linear; or with the signs for degrees and minutes, if of direction.

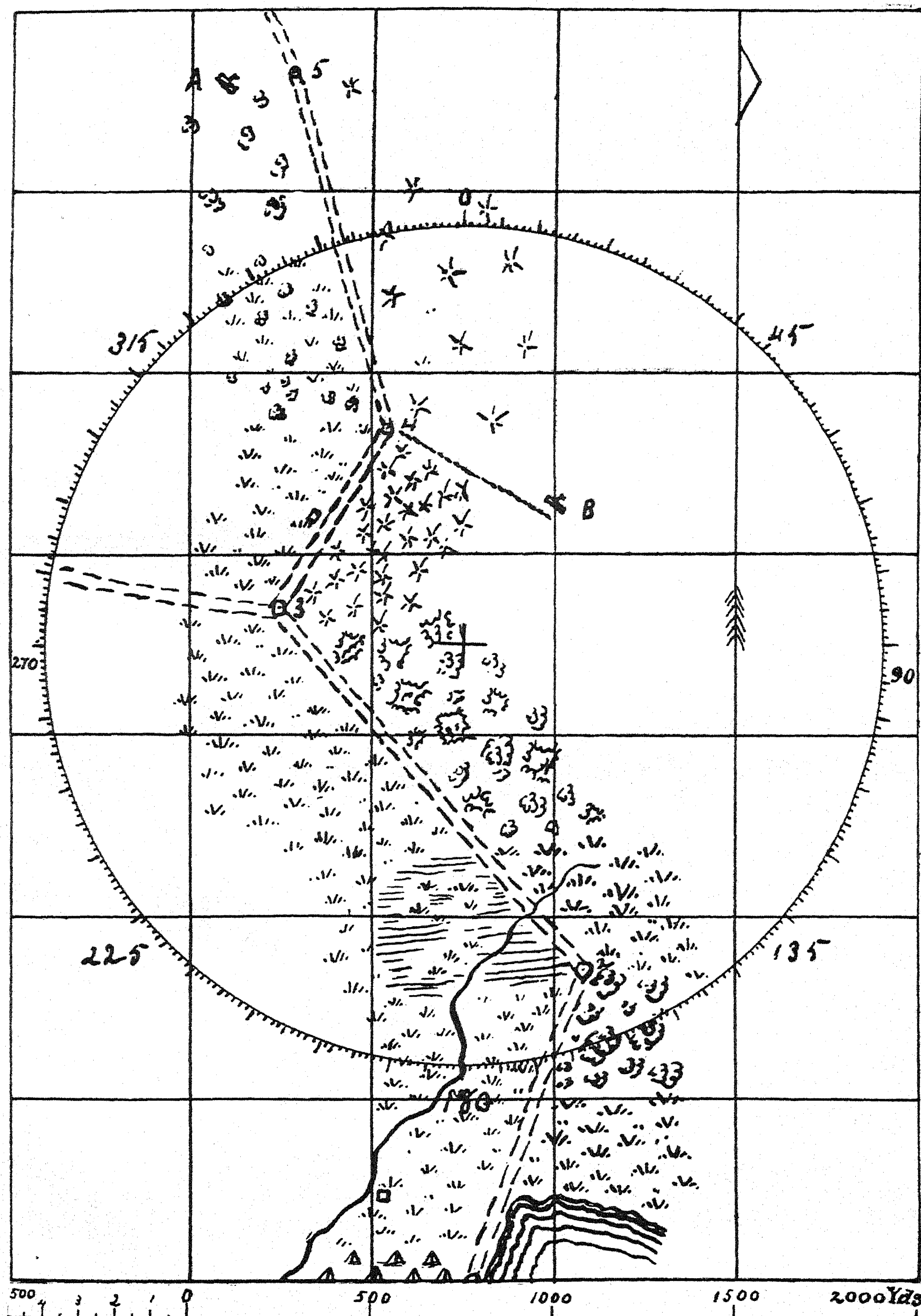
The point of beginning, as well as each station where the course changes direction and is observed by the compass, is marked by a dot with a circle around it, in the center column, and designated with its proper number by its side.

PLATE A.

Remarks Left.	Offsets Left.	Courses and Distances	Offsets Right.	Remarks Right.
Picket A.	200	$\odot$5.		Steep slope towards enemy
		1000.		
				Road steep.
Scattered trees				Scattered pines
		345°		
Cleared land.		$\odot$4	500	Trail to Picket B, bearing 120°
		600		
Wooden house	35	300		
		30°		
Dirt road, unfenced. to		$\odot$3.		Woods (pine)
Newton, dist 8m, Bears 280°		1300		
Meadow				Woods (mostly oak)
Marsh ends.		400		Meadow ends
Forded Creek.		200		Stream flows 220°
		320°		Meadow
Marshy.		$\odot$2.		Woods end road good
		900		
Creek	115	600		Woods
				Meadow
Creek stone house on left bank	165	250		Left lake shore. Bearing of edge of lake 100°
		20°		Left camp followed unfenced
Meadow.		$\odot$1.		road parallel to lake shore.

Bearings taken with Box compass graduated contra-clockwise.
Distances in Yards.
0° of Compass at North.

PLATE B.



After the last forward distance of a course is recorded, a line is drawn just above it across the distance column, then the new station sign and number are entered, and above these the new direction.

The entries in the "Offsets" and "Remarks" columns are made on the same horizontal line as the record of the forward distances in the center column of the points of observation.

In the columns of "Remarks" are recorded the directions of objects too distant to be located by offsets, and such other remarks as may be pertinent.

Sketching. The sketching, which is to be merely an assistance in subsequently plotting accurately, should be performed as the traverse proceeds and should be as full as possible. The blank protractor, printed on the right-hand page, should be marked to correspond to the *protracted readings* of the compass used, as described for marking the diagrams, and the record on the left-hand page should be made exactly as observed; then a line through this reading and the center of the protractor will be parallel to and indicate the direction of the course. The meridian line should always be put on the sketch in such direction and the sketch begun at such point as to permit of putting as much of the traverse as possible on each page.

Having taken the first forward direction, and recorded it in the center column just above the station sign 1, a line is drawn on the right-hand page, from the point selected for the first station, parallel to a line from the center of the printed protractor to the number corresponding to the direction of the course. This will be the plotted direction of the first course. The surrounding details, by offsets, are then recorded and sketched in to scale, either by measurement or estimation. Pacing or measuring forward, being careful to preserve the alignment on the object sighted with the compass, is then begun and continued until the sketcher arrives opposite some offset which he wishes to note, when the distance to this point from station 1 is recorded in the center column at the esti-

mated distance to scale from the station. On the same horizontal line in the "Offsets" column, on the right or left of the center column, depending on which side the object is situated, is recorded the perpendicular distance of the object from the traverse line, and in the column of "Remarks" such information is added as may seem necessary. On the right-hand page, at the distance of the offset from the station point to scale, on the line drawn a dot is made, and on a line through this dot perpendicular to the course the object noted is sketched in at its offset distance. This completed, the pacing forward is resumed, beginning with the number recorded from the station up to this point, and not with 0. This is continued until the point sighted or the end of the first course is reached, when the total distance from the station is recorded at its distance to scale in the center column. A line is then drawn across the column just above this last recorded distance, and the station sign made and numbered just above the line.

The total distance to this point is then laid off to scale on the line representing the course on the sketch, a dot made, surrounded by a circle and numbered.

The next forward direction is observed and recorded, the surrounding details recorded and sketched in, the pacing to the next station begun, the counting beginning again at zero, and so continued to the end of the traverse.

To plot the notes from the Field Book on the final sheet that is to contain the map, plot from the point for the first station the first forward direction with a protractor, and on this lay off to scale the total measured distance to the second station. From here plot the second direction and lay off the total distance to the third station, and so on in succession to the end of the traverse. If this latter has been run from one already determined point to close on another, it can be determined by the above method whether it closes satisfactorily, before proceeding to plot in the details. Next return to the first station, lay off on the courses the intermediate forward distances recorded in the center column, from each back station, and

from these points the corresponding offset distances perpendicular to the traverse line, thus locating the positions of details, such as the sides of a road, if the traverse has been along one, houses, ponds, etc. For laying off the offsets, a scale should be constructed on the edge of a card and numbered each way from the center. The position of the paper should be shifted so as to always keep the direction of each course on it corresponding to the direction of the center column in the Field Book, to avoid laying off offsets on the wrong side of the traverse. Constant reference should be made to the rough sketch on the right-hand page.

A modification of the foregoing method and one requiring greater skill, that is applicable when no scales have been constructed, when neither note-book nor protractor is available and the field work must be done rapidly, consists in using a sheet of cross-section or ordinary ruled paper folded bellows-like, the sketch beginning in the middle of the last fold and running forward through the book, which is held side-wise, the ruled lines being perpendicular to the traverse. Work done in this manner must be plotted afterwards to scale, data for the construction of which may be obtained at any time previous to plotting, so that but a brief description of the field work will be given, as follows:

Standing at the initial point, take the bearings of all roads and plot them by eye on the last page of the folded sheet while holding the paper before you so that its length is in the general direction of the route to be traversed, then write the bearings on the lines so drawn and sketch or write in such detail as is required.

Traverse to the second station and plot your position approximately to scale—*i. e.*, call four of the intervals between lines 100 strides, whether at a walk or trot, or a minute if time scale is used. Sketch in the usual details, such as houses, fences, contours, streams, bridges, etc., and be sure to number the successive stations consecutively, *writing on edge of page opposite each station its exact distance counting from previous station.*

Do not use compass for slight changes of direction, but depend on the eye after orienting by the back station. Estimate steepness of all slopes and sketch in contours as accurately as practicable. After completing the field work, a fair copy of the map is made, plotting the recorded steps or time accurately to scale, and protracting such angles as were measured.

TRAVERSING WITH COMPASS AND DRAWING-BOARD.--This consists in observing the directions and measuring the lengths of the courses of a traverse, and determining the positions of adjacent objects and plotting them accurately at once to scale on a sheet of paper in the field, instead of entering them in a note book to be subsequently plotted.

Preparing paper. A piece of drawing-paper, of a size depending upon the length and shape of the traverse and the scale of the drawing, is fastened upon a small drawing-board, which is carried in the hand, and should be turned so that the forward direction of a course corresponds in direction with the line on the ground which it represents. The same principles which govern one in taking notes when traversing with a note-book are applicable when traversing with the drawing-board. The paper should be ruled, before starting out, with parallel lines from $\frac{1}{3}$ to $\frac{1}{4}$ of an inch apart and one end marked with a half arrow-head to indicate north. A diagram of the compass readings should be made in one corner.

Fixing initial station on paper. If the traverse is not already fixed by known and plotted points, then to determine at what point on the paper to begin plotting to include the greatest amount, some knowledge of its directions and length should be had; otherwise a decision must be made after taking the first direction and referring it to the diagram. Thus, if south be taken at the upper part of the paper, and the first direction is only a few degrees from the south and it is known that the general direction of the traverse is to the southwest, then the starting-point would be fixed near the lower left-hand

corner. The sketcher must exercise his judgment in properly placing his work.

Field work. Having decided upon the point for the first station, the first direction is protracted by a line lightly drawn, the surrounding details accurately plotted and sketched in, and the pacing or measuring to the next station begun, the sketcher stopping from time to time to take offsets and sketch in details as he arrives opposite them.

The position of an object too distant to fix by an offset may be determined by two sightings taken to it at different points of the traverse. Unnecessary prolongation of lines should be erased to avoid confusion. All points marking the end of the different courses or stations should be surrounded with a circle to avoid the common error of laying off distances from the wrong point. As previously stated, the counting of paces, after halting to sketch or measure an offset, is resumed at the number reached at the time of stopping, and not at zero. On starting out from a new station in a new direction, the counting begins again at zero.

Sketching with the compass and drawing-board should be conducted as with the plane table, without tripod, in which the compass takes the place of the alidade for determining the directions of objects. Although protracting them is a more troublesome and less accurate process than drawing them with the alidade, both are intended to accomplish the same result in the end.

Or, instead of using the compass for determining the directions of objects to be subsequently plotted, it may simply be used to orient the board and keep it in this position, while the directions of objects are obtained by sighting along the ruler, as will be explained in sketching without instruments.

These lines should not extend clear across the board from the point of observation, but a short line is drawn at about the estimated distance of the object, and then marked to identify it. It will be well to have a meridian line on each side of the sketch, so the compass can be under the eye while holding the

board to sketch, no matter which side is next the body. Should there be local attraction at any point, it can be detected by sighting to any already plotted object, after orienting the board with the compass. If such be found, the board may be oriented by a back-sight, as already explained, and the work proceed. Such attraction would probably not be noticed until too late to make correction if directions are observed with the compass and plotted with the protractor. While sighting, the board should neither be strapped to the person nor hung against the body by a string around the neck, but should be held so as to be readily turned in any required direction, by resting it upon the forearm, grasping the edge firmly with the fingers and pressing it against the arm and body, or by holding it upon the tips of the fingers of one hand.

TRAVERSING WITH THE FIELD SKETCHING-CASE.—*Description.* *The field sketching-case** (Fig. 208) is a small pat-

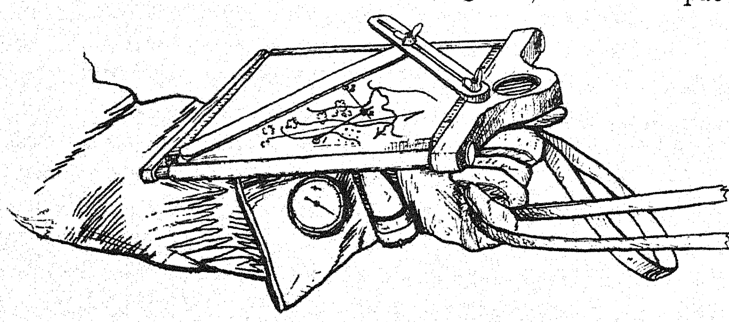


Fig 208.

tern of the old-style plane table drawing-board in which the compass for orienting the table was "set in" on one side, and the paper fastened on rollers at the ends. It is about $8\frac{1}{2}\times10\frac{1}{4}$ inches in size, has a roller and clamp on each side for holding the paper, and a compass sunken flush in the head. On the

* In nearly its present form and size it is the invention of Col. W. H. Richards, for many years Professor of Military Topography at the Staff College, Sandhurst, England, and author of "Text-Book of Military Topography."

glass of the compass box is marked a *meridian line* with an arrow-head for the north end; the needle must always be brought, by turning the case, to coincide with this meridian line, with its north end under the arrow-head, whenever plotting a direction.

Instead of the alidade of the plane table, there is used an ordinary straight-edged ruler of some kind, or, as shown in the cut, an arm attached to the head, and a sliding universal ruler, on the edge of which is marked the working scale.

On the under side of the case is a semi-circular protractor and plumb for use in connection with the foot of the case in determining the degree of slopes, as described for the slope board. To use it, sight along the foot-piece, holding the case so the pendulum will swing freely till oscillations cease; then tilt case to the right until pendulum rests on arc, and read. There is also a strap on the back for holding the case in the hand if used on foot, or for fastening it to the bridle wrist, if used on horseback.

As thus constructed, it has, after a fashion, all the apparatus of a plane table, except the levels, and is used in every respect like the plane table. With it the making of rapid sketches is greatly simplified and facilitated. The degree of accuracy which it is possible to attain with it by a little care and attention is quite remarkable.

To put on paper. The case will hold a strip of drawing-paper about 7 inches wide by 3 or 4 feet long, which is put on by first making a fold across each end about $\frac{1}{3}$ of an inch wide, truly perpendicular to the length. Holding the case in front of the body, with the compass to the right (normal position), pass one end of the paper down between the board and the roller farthest from the person, bring it up outside the roller, and put the fold on the end in the slit in the roller; holding the end there, turn the roller until all but about 8 or 10 inches of the paper is rolled up, then clamp the roller and stretch a rubber band from the opposite side of the compass head across the roll of paper to keep it from uncoiling. Pass

the other end of the paper across the top of the board, down between the board and the roller next the person, up outside, and place the fold in the slit in the roller, and roll it up until the paper lies flat and smooth across the board; then clamp and remove the band.

To draw the meridian. The compass box can be turned around in the case in order that the meridian line on the glass may be given such a direction with reference to the sketch that the *general* direction of the traverse will lie near the central line of the paper. This is determined by holding the case in normal postion, laying the ruler across the middle of the two rollers, and turning the case until the end over the far roll of paper points in the general direction of the traverse. The compass box is revolved, without changing the position of the case, until the meridian line is directly over the needle, with the arrow-head over the north end.

A meridian line is next drawn on the paper parallel to that on the glass, and the north end marked corresponding to the arrow-head.

A number of lines are drawn on the glass cover parallel to the meridian line to assist in drawing the meridian line on the paper, by placing the edge of the ruler parallel to one of these lines. This operation, it will be observed, is the same as marking a meridian line on the plane table sheet with a compass or declinator to orient the table by, as described. After this, the compass box must not be moved so long as the traverse will remain on the paper.

If the traverse or route be indicated on a *furnished map*, the meridian line can be set in the required relation to the sketch. To do this, the magnetic meridian, if not already on the map, is drawn on it, the sketching-case with the drawing-paper on it is laid on the map so that its length shall correspond with the general direction of the traverse line, while the compass box is turned until the meridian on the glass is parallel to the magnetic meridian on the map.

Field work. To begin the traverse, stand at the first sta-

tion, face exactly towards the second station, bring the case level in front of the center of the body and revolve it until the meridian line on the glass is exactly over the needle, arrow-head over the north end. The oscillations of the needle may be checked by tilting the case slightly, but the case must be level and the needle free when the direction is finally taken.

Next bring the point from which the line is to be drawn in front of the center of the body by moving the arm, but without turning the case. Lay the ruler on the paper with one edge on the point and direct the other end of the ruler towards the object ahead, glancing at the meridian line to see that it still corresponds with the needle, and that the latter is free; place the little finger of the pencil hand on the ruler, if it is not weighted or otherwise arranged not to slip; then draw the line or make a dot at the further end, and afterwards join the points by a straight line. If, on glancing at the meridian line, it does not correspond exactly with the needle, it may be made to do so by a slight movement of the wrist. The alignment of the ruler on the object may be done by looking at the object intently; then, by dropping the eyes without moving the head, trace an imaginary vertical line through the object and point on the paper, with which make the edge of the ruler through the point coincide, or by fastening one end of a thread, with a bullet on the other end, to the cap visor in front of the eye.

With the case still oriented, sightings are next taken to all prominent objects too distant to be located by offsets.

Traversing towards the second station is then begun, stopping from time to time to locate and sketch in details to the right and left as they become perpendicular to the traverse line.

On reaching the second station the length of the first course is laid off to scale, the case is oriented by revolving it until the meridian line on the glass comes over the needle, the direction of the second course, from the second to the third

station, is drawn as before, and the work carried on in the above manner to the end.

If the sketching-case is used *on horseback*, the operations are exactly the same as described above. To draw a direction, the horse is turned facing exactly in the direction of the object to be sighted, the case oriented, and the line drawn as before. A horse will generally stand still long enough for this.

As the sketching approaches the far roller, the sketch is rolled up on the near roller and fresh paper brought upon the board.

Should the traverse, either because of a change in its general direction or because the meridian line was not given a proper direction, run off the side of the paper, sketching is stopped and a line drawn there across the paper. The case is turned in the new general direction of the traverse, as was done on commencing, the meridian line on the glass turned until over the needle, thus altering it to suit the new direction, and a new meridian line drawn on the fresh portion of paper parallel to the meridian line on the glass. The sketch is commenced in the center of the paper and 2 or 3 inches above the line drawn. If the running off is due to some *local* change of direction, and the general direction of the traverse still coincides with the central line of the paper, the meridian will usually remain unchanged.

Instead of making the alterations of meridian at the end of a course where there is a change of direction, it is better to proceed along the next course for a distance a little greater than the distance to which offsets are sketched in, and there make the change, thus avoiding the duplication of details in the smaller angles between the courses at the station, and the omission of others in the larger angle.

These alterations of the meridian may have to be made several times, but the necessity therefor should be avoided as much as possible by proper arrangement.

To finish the sketch. If it has been necessary to change the meridian, the paper is cut across the lines where the

changes were made, the corresponding points of stopping and recommencing the sketch are made to coincide by sticking a pin through them into a board, the pieces are turned until their meridian lines are parallel, then firmly pinned in this position and both cut through with a sharp knife, passing through the coinciding points. The two pieces are then united by a strip of paper pasted on the back along the cut edges. When all are thus united, the traverse will follow along the middle of the irregularly shaped strip. This may then be mounted, if desired, on another piece of paper by its edges, and placed under a heavy weight while drying.

Sketching-pad. For the field sketching-case, satisfactory results have been obtained by using a pad of suitable size, of good paper, backed with heavy cardboard, the paper being attached on all four edges. On the back of the pad is fastened a loop of leather for carrying and holding it while sketching. On one edge of the pad is rigidly attached by clamps a compass in a wooden head and the rulers, giving it the appearance of the sketching-case (Fig. 208), without the rollers. For a clinometer, the ruler is used as a plumb in connection with a properly graduated line or arc on the opposite side of pad from the compass.

As thus arranged, the sketching-pad is used in every respect as has been described for the sketching-case, except that as each sheet of the pad is filled, it is torn off and put in the pocket, and another one filled, etc.

TRAVERSING WITHOUT INSTRUMENTS.—*Making the scale.* A sheet of paper is fastened on a piece of smooth board or lid of a box, and a straight-edged piece of wood is provided for a ruler.

The sketcher decides on about the *scale* he wishes to use, then takes a strip of paper of about the length he calculates will represent say 800 to 1,600 paces and folds it three or four times, thus dividing it into 8 or 16 equal parts, each representing 100 paces; these he uses or draws them on the edge of a card for laying off his distances. The smaller distances than

100 paces he can divide by estimation. He can also estimate his offsets in his paces and use the same scale or construct a scale of yards from his scale of paces already made. The representative fraction corresponding to his scale can afterwards be determined when he has access to a scale of equal parts.

Field work. The system to be followed is that which has been already described for traversing with the plane table when orienting by back-sights instead of by the compass. The legs of the plane table have to be dispensed with and the board is laid as nearly level as possible upon the ground. Stations and prominent objects are located by intersection, the ruler being pivoted on the point on the sketch representing the position of the board on the ground. *The ruler is aligned* on the different objects whose directions are desired by standing a little distance behind the board and holding the lead pencil vertically several inches in front of the eye and moving sideways until it is in the vertical plane through the object and station point, then noting which way and how much to revolve the ruler, making the alteration, sighting again and altering until aligned; or a stone tied to a string, forming a plumb-line, may be used for determining the vertical plane through the object and station point, and aligning the ruler. The surrounding details are sketched in, then the traversing forward to the next station is begun.

When stopping at any time to sketch in details as he arrives opposite them, or on arriving at a station, the sketcher *orients his sketch* on the back station by placing his ruler along the plotted direction of the course on the sketch, and then, standing behind the board, he determines the vertical plane through the back station and the plotted point of his position, and moves the whole board until the edge of the ruler coincides with the pencil or string defining this plane. Having the board oriented, sightings may be taken to important objects as before. If at a station where a change of direction is to be made, the forward direction is drawn and the traversing continued. Whenever possible, the board should be oriented

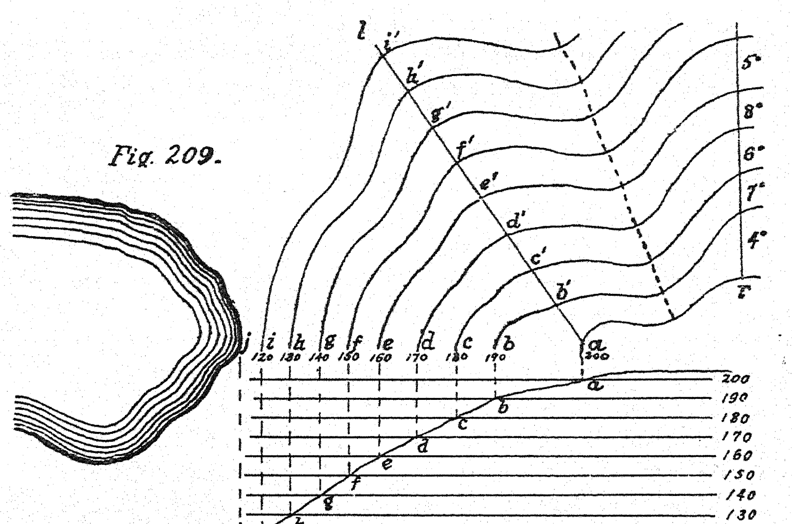
on the most distant visible objects whose positions have already been fixed on the sketch, rather than by the short back courses. The edge of the ruler is laid on the two plotted points of the distant object and sketcher's position and the board turned until the ruler points to the distant object. The whole operation is nothing more than crude plane table work, and one who can use the plane table will find little difficulty in applying the same principles here.

The true meridian may be approximately laid down on the sketch by determining it at noon from the sun as previously explained.

The sketcher can at any time find his position by resection as with the plane table under the same conditions.

SKETCHING HILL FEATURES.—Contours carry the greatest amount of information with the least amount of drawing in the field, but to sketch them intelligently it is necessary to have a clear idea of the shape of the features and a good mental picture of the appearance they will present in plan.

Fig. 209.



Supposing stations to have been intersected, and houses, woods, streams, roads, fences, and other details to have been sketched in by traversing, the operations of sketching the hill features will be much simplified since the directions of water-sheds and water-courses, etc., can often be recognized by reference to the details already drawn, without other measurements.

Suppose the sketch to be made on a scale of R. F. $\frac{1}{5000}$ and hill features to be shown by contours at 10 feet contour intervals. Prepare a table of H. E.'s as follows: 10 feet at 1° =573 feet, 2°=286 feet, 3°=191 feet, 4°=143 feet, 5°=115 feet, 6°=95 feet, 7°=82 feet, 8°=72 feet, 9°=64 feet, 10°=57 feet, or draw a scale of the same.

To sketch a spur one might, when standing at A on the ground (Fig. 209), whose height above datum has been determined, or assumed, to be 200 feet, observe the slope with his clinometer to be 3° in the direction of a pond. Referring to his table or his scale of horizontal equivalents for 10 feet C. I., he would find the H. E. for 3° to be 191 feet. He paces 191 feet down to B and plots 191 feet to scale on his sketch or lays off the H. E. for 3° from his scale of H. E., fixing the contour point *b*.

Change of slope at contour. Supposing the slope changes at B, a contour point, he observes it to be 7°, the H. E. of which is 82 feet. He paces 82 feet to C and lays off from *b* the H. E. for 7° from his scale, fixing the contour point *c*. The slope remaining the same for some distance, he continues pacing down distances of 82 feet, stopping to plot each on his sketch; or, what is simpler, he paces from C down to E, where the slope again changes, and finds he has paced 246 feet, or 3 times 82 feet, and he lays off three distances of 82 feet, fixing the contour points *c*, *d*, and *e*. At E he observes the slope to be 9° to the pond, already sketched in, so he merely measures off the H. E. of 9°=64 feet as many times as it will go into the distance, it being unnecessary to pace the distances, thus fixing the points *f*, *g*, *h*, and *i*.

The line along which he has descended is termed a *section line*.

When standing at A, he also observes with his clinometer that on the section line AL the slope of 6° is uniform for some 250 yards, so he marks off in that distance the H. E. of 6°=95 feet, fixing the points *b'*, *c'*, *d'*, etc., at the same levels as *b*, *c*, *d*, etc., and draws the contours joining these points.

With his clinometer he also finds points on the same level as A, from which he can observe the slopes and set off other points on the same levels as *b*, *c*, etc., and join them to these, paying attention to the form of the intermediate ground.

Change of slope between contours. In the preceding discussion, the slopes were supposed to change exactly on the contour points B and E, but this would seldom be the case in actual practice; nor can any exact spot be said to be the point of change, as the slopes change gradually from one to another. By practice, however, a mean can be struck and the difficulty overcome.

1st method: Suppose (Fig. 210) the first slope *ab* to be 5°, the H. E. of which is 115 feet. Pacing 115 feet from *a*, he arrives at *r*, which he lays off from *a* on his sketch with his scale, fixing *r*. The slope being the same beyond *r*, he continues pacing to *b*, about where he judges it to change. The distance *rb* being 58 feet, or $\frac{1}{2}$ of 115 feet, he has descended $\frac{1}{2}$ a contour interval, or 5 feet. The new slope he observes to be 3°, on which he must descend $\frac{1}{2}$ a contour interval to reach the next contour point. The H. E. of 3° being 191 feet, he paces $\frac{1}{2}$ that distance, or 95 feet, and locates *s*. From here he paces 128 feet to *c*, where the slope again changes to 6°. Now 128 feet is the H. E. of $\frac{2}{3}$ the contour interval of 3°; hence he has descended $6\frac{2}{3}$ feet from *s* and he must descend $\frac{1}{3}$ of a con-

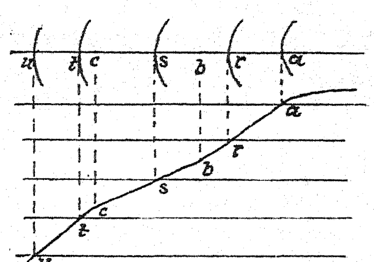


Fig. 210.

tour interval on the 6° slope to arrive at the next contour point. The H. E. of 6° being 95 feet, $\frac{1}{3}$ will be 32 feet, which he proceeds to pace, and lays it off on his map, locating *t* and so on.

2d method: This process is, however, long and troublesome, but after some experience one becomes accustomed to judging about where the positions of the different points *s* and *t* come, 10 feet below the preceding one, then measures the slope to them with his clinometer and paces down a distance equal to the H. E. corresponding to it, thus making allowance for any slight change of slope in observing it. This is of course easy when the slope is concave in section, as from *a* to *c*, but should it be convex, as from *s* to *u*, it would be more difficult, though after some practice one may form an idea of the approximate position of the contour point, if not too convex, and observe the slope accordingly. If the section be very convex, this might be impossible and the first method explained have to be used.

Contour Working Table. The operation of sketching hill features is much facilitated by the use of the *Contour Working Table*, which is a personal table filled out by each sketcher after he has determined the length of his stride. Assuming the length of the sketcher's stride to be 60 inches, the following table gives the number of strides (to the nearest tenth of a stride) for slopes from 1° to 12°, inclusive, and for vertical intervals from 1 foot to 15 feet, inclusive. Similarly for any other length of stride the table may be constructed by finding, from the formula $HE = \frac{VI \times 57.3}{S}$, the number of strides for a slope of 1° and a vertical interval of 1 foot; dividing this result by 2, 3, 4, etc., the number of strides for the same vercal interval and a slope of 2°, 3°, 4°, etc., will be found. Multiplying these results by 2, 3, 4, etc., the vertical columns are filled in.

CONTOUR WORKING TABLE FOR VARYING SLOPES.

Length of stride 60 inches.

NUMBER OF STRIDES.						CORRESPONDING VERTICAL INTERVALS.
SLOPE 1°	SLOPE 2°	SLOPE 3°	SLOPE 4°	SLOPE 5°	SLOPE 6°	
11.5	5.7	3.8	2.9	2.3	1.9	1 Foot.
22.9	11.5	7.6	5.7	4.6	3.8	2 Feet.
34.4	17.2	11.5	8.6	6.9	5.7	3 Feet.
45.8	22.9	15.3	11.5	9.2	7.6	4 Feet.
57.3	28.7	19.1	14.3	11.5	9.6	5 Feet.
68.8	34.4	22.9	17.2	13.8	11.5	6 Feet.
80.2	40.1	26.7	20.1	16.0	13.4	7 Feet.
91.7	45.8	30.6	22.9	18.3	15.3	8 Feet.
104.1	51.6	34.4	25.8	20.6	17.2	9 Feet.
114.6	57.3	38.2	28.7	22.9	19.1	10 Feet.
126.1	63.0	42.0	31.6	25.2	20 1	11 Feet.
137.5	68.8	45.8	34.4	27.5	22.9	12 Feet.
149.0	74.5	49.7	37.2	29.8	24.8	13 Feet.
160.4	80.2	53.5	40.1	32.1	26.7	14 Feet.
171.9	86.0	57.3	43.0	34.4	28.7	15 Feet.
SLOPE 7°	SLOPE 8°	SLOPE 9°	SLOPE 10°	SLOPE 11°	SLOPE 12°	
1.6	1.4	1.3	1.1	1.0	1.0	1 Foot.
2.3	2.9	2.6	2 3	2 1	1.9	2 Feet.
4.9	4.3	3.8	3.4	3 1	2.9	3 Feet.
6.6	5.7	5.1	4.6	4.2	3.8	4 Feet.
8.2	7.2	6.4	5.7	5.2	4.8	5 Feet.
9.8	8.6	7.6	6.9	6.3	5.7	6 Feet.
11.5	10.0	8 9	8.0	7.3	6.7	7 Feet.
13.1	11 5	10.2	9.2	8.3	7.6	8 Feet.
14.7	12.9	11.5	10.3	9.4	8.6	9 Feet.
16.4	14.3	12.7	11.5	10.4	9.6	10 Feet.
18.0	15.8	14.0	12.6	11.5	10.5	11 Feet.
19.6	17.2	15.3	13.8	12.5	11.5	12 Feet.
21.3	18.6	16 6	14.9	13.5	12.4	13 Feet.
22.9	20.1	17.8	16.0	14.6	13.4	14 Feet.
24.6	21.5	19.1	17.2	15.6	14.3	15 Feet.

To use the table. Suppose the sketcher, while sketching with a contour interval of 15 feet, after having gone down a 2° slope a distance of 63 strides from the last contour point, comes to a change of slope. He looks down the column headed "Slope 2°" until he comes to the number of strides taken, and then horizontally across to the corresponding number of feet in the column headed "Corresponding Vertical Interval" and finds that he has descended 11 feet. He has therefore a further descent of 4 feet to make before he reaches the next contour point. He observes the new slope and finds it to be 6°. Looking in the column headed "Slope 6°," and opposite 4 feet in the column headed "Corresponding Vertical Interval" he finds that he must take 7.6 strides to reach the next contour point. On a uniform slope this table may be used in connection with the scale of strides in precisely the same manner as a *table* of horizontal equivalents.

In case of a *knoll* rising in front of a sketcher as he descends from the high ground (Fig. 211), he continues to the lowest contour g in the saddle, then with his clinometer finds where this contour would strike the knoll at g', paces across to it, then over the knoll until he finds g'' on the same level as g and g', from which point he resumes his locations of points for contours h, i, etc.

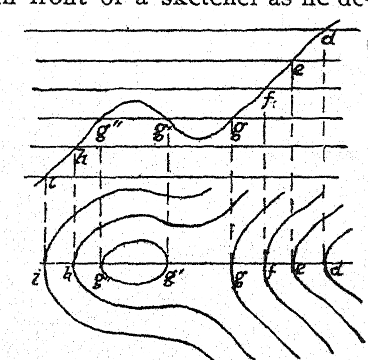


Fig. 211.

It is better to *begin contouring from high ground* and follow the section lines down hill, because a more extended view of the ground can be obtained, the formation of the features can be more plainly observed, and the directions of watersheds and water-courses can be more easily determined. Cases may arise where one will have to *start* from low ground, as, for example, when a bench-mark or large body of water fur-

nishes a convenient level from which to start. Even in this case, however, the high ground is reached as soon as possible and the work continued from there.

When one halts on a contour to sketch it in, he should generally face about and orient his sketch, and then put in the contour to his right and left as far as it is in view. He may at first have to search the ground with his clinometer set at 0° in order to recognize his level, or even back down hill until his eye is on a level with the contour point, but with practice he will soon learn to dispense with this assistance.

Before drawing contours, it is a good plan to *indicate by dotted lines* the estimated positions of water-courses (Fig. 209) which bound the feature. These can usually be seen and their distances judged on either side from the water-sheds.

In sketching, the distances of features up to 100 yards are usually estimated, and one should have impressed upon his mind the space, according to his scale, which such small distances will occupy, and not have to refer to his scale each time.

When the *features are very large* and the position of a contour can be observed to the right and left for a distance of a quarter of a mile or more, it is well to take its direction with the compass, sketching its distance by estimation, subject to correction later.

The section lines should follow the water-sheds, if possible, as more or less of a view is obtained from them to the water-courses on each side. With this end in view, it may be necessary to alter the direction of the section lines from time to time, so as to follow them, since water-sheds seldom run in straight lines. In many cases the direction can be referred to distant objects which have already been sketched in, thus avoiding the necessity for observing it with a compass. Thus, it is noticed that the section line *ab* (Fig. 212) passes a little to the left of the house T, already sketched in, and so it is drawn. At *b* it changes and passes through the corner of the fence at K, and is so drawn. At *c* it again changes, passing to the left of the pond R. From *h* it passes to the right of the orchard, at *i*

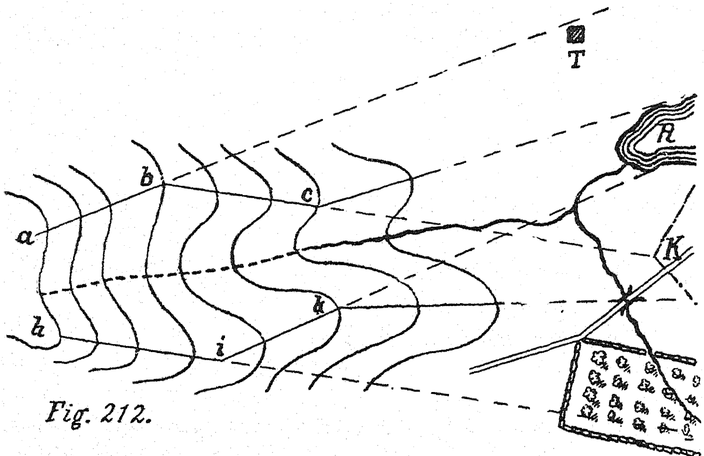


Fig. 212.

changes to the right of the pond, and at *k* it passes through the bridge. This is sufficiently accurate, in sketching, for the purpose of tracing the direction of the imaginary line of a water-shed.

Reference points. The preceding descriptions have dealt with some of the processes of sketching *single* features only. If there are a number of such features to be sketched, and it is desired to make the contours of all unite and be continuous, *one must arrange to begin sketching the contours of each feature at some level common to the others.* To do this, he may, when standing on his first contour, suppose at A (Fig. 213), use his

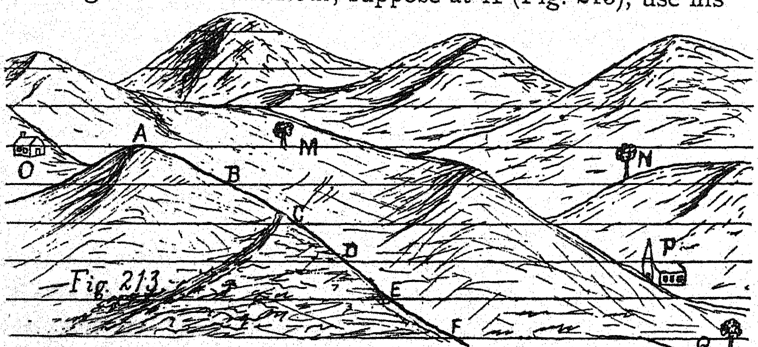


Fig. 213.

clinometer as a level and find several conspicuous objects on the different features within a half mile or so, on the same level as the point from which he is going to begin. For instance, he may find that the foot of the tree M on one feature, the top of N on another, and the eaves of the house O on another are all on the same level with A.

These points M, N, and O are called *reference points*, and a note made of them on the margin of the sketch for future use. At any time while sketching, if A, M, N, or O happens to be in sight, he can place himself on their level by setting his clinometer at 0° and moving up or down hill while sighting the visible reference point until the clinometer indicates that he has reached such a level. Having done this, he can then find his place on the sketch by *resection* and commence sketching in the contours of the feature he is on, both above him and below him, with the certainty that they will join on the same numbered ones of adjacent features and be continuous for all.

When the hills are of considerable height, *reference points* should be found and noted at every 50 or 100 feet elevation, in order to furnish the sketcher with a ready means of placing himself on a known level at any point where he may be, instead of his having to go back to the level at which he began, which might be either impracticable or inconvenient. Thus, suppose the positions of the contours to have been found at B, C, D, E, F, etc., on the first section line AF. On arriving at D, and looking around with the clinometer set at 0°, the ridge of the church P is seen to be on the same level, and a note is made of it; when arriving at F, the underside of the leafy part of the tree Q is found to be on a level with it, which is recorded, and so on.

By thus selecting *reference points* at different levels, some one of them will probably be in view from almost any part of the field, thus furnishing a means at all times and at any place for beginning to sketch the contours so they will be continuous.

In some places there may be natural levels common to the

whole ground, presenting well-defined crests and so nearly level as to furnish a contour common to the whole section, and very convenient for starting from to sketch in the lower contours.

When sketching hill features *in bad weather or when time is not available for doing so with accuracy*, they may still be shown with some degree of truth, provided the traversing has been performed, or one is able to find his place at any time. He visits some of the most prominent features (Fig. 214), finds

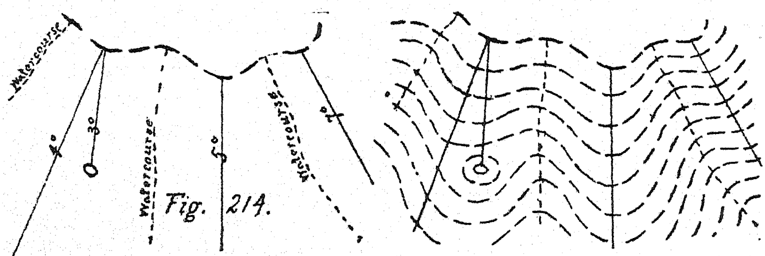


Fig. 214.

his place by *resection*, marks the forms as well as he can on the sketch, and writes on them the vertical angles which he observes with his clinometer to some one central feature or object which is or can be located on the sketch. If the positions of the water-courses are already drawn, or if he can draw them, then he can sketch in his contours later from the data thus obtained.

Sometimes small but important features lie between contours, untouched by them; they may be shown by dotted lines to distinguish them from the contours.

Form lines. Should time not be available for sketching contours common to the whole area, or the country be much wooded, or the sketch be of such a nature (as, for example, a road sketch) as to make it impossible to follow the methods described, the hill features may still be shown by what are known as *form lines*, which consist of contours at the given contour interval for each feature, but which are not drawn to join those of adjacent features, nor to show the same levels above a given datum. They simply refer to the features which

they represent and have no connection with those of adjacent features.

SKETCHING MOUNTAINS.—On account of the difficulties in measuring distances by pacing, the preceding methods must be modified somewhat in sketching mountains.

The base-line. In arranging for the intersections for control points, the base is usually measured at the foot of the mountains. Where the slopes terminate in deep ravines, however, from which no view can be obtained, it becomes necessary to go up higher, perhaps even on top, or on a water-shed where a more suitable base can be found. In this work a good telemeter will be of great assistance, for with it a base may be measured between convenient points, though the ground between be rough and filled with obstacles. And if several trials are made and the *mean* taken for the measurement, a closer approximation to its true length would probably be obtained than could be done by pacing on fairly level ground. Or, from a single point the distance could be measured between two distant points which were considered desirable for stations.

Location of points. From the ends of the base, the highest and most sharply defined peaks would be located by intersection. From these, less important knolls, etc., can be located by resection during the progress of the work.

Vertical interval. On account of great differences of level occurring in small horizontal distances, *the vertical interval* between contour planes must be considerably increased. In the survey of the Rocky Mountains, contour intervals have been as much as 250 feet. In other cases contour intervals have been 50, 100, and 200 feet, depending upon the character of the mountains.

The *levels of important and accessible points* may be obtained by using the aneroid barometer, and the *less important and inaccessible ones* by measuring the vertical angles from some one or more points whose elevations have been already determined.

The clinometer may be used *to determine the difference of level between two points, when the horizontal distance between*

them is known. Thus, suppose two points have been plotted and the vertical angle of one is observed 5° elevation from the other. Suppose the contour interval 15 feet and the distance between the two points is found to be 1,350 feet. From the table of horizontal equivalents, it will be found that a difference of level of 15 feet occurs at 5° every 171.9 feet; hence one point is above the other $1350 \div 171.9 = 7.85$ contour intervals $= 117.75$ feet.

Instead of making the above calculation, if the horizontal equivalent for 5° as found on the scale be applied to the distance between the two points, it will be found to go almost 8 times, indicating *the number* of contours, but their *grouping* will be arranged according to the steepness of the slope in different parts. If the slope is steepest near the top, the contours will be grouped closer together there and farther apart near the bottom.

The accuracy of this method depends upon the accuracy of the plotted distance between the two points and the angle as taken with the clinometer. Should an opportunity occur for observing the angle of depression from the other point, the number of contours between them could be checked.

This application of the clinometer is particularly useful in very hasty work (from any cause, as bad weather, want of time, etc.) as described.

COMBINATION OF THE DIFFERENT STEPS.—Having practiced the different operations of sketching *separately*, and having become proficient in them, one can *combine these operations*, and not have to visit any portion of the ground twice. Thus, beginning at a point from which an extended view can be obtained, the directions of a few prominent distant objects, such as houses, trees, etc., will be determined, either plane table fashion or with the compass, and drawn on the sketch with the names of the objects written on the margin. Selecting another good point at some distance for the other end of a base, he can, if he has a telemeter, measure the distance to it; otherwise he proceeds at once with the traversing towards it, select-

ing as long courses as possible. Arriving at any point from which a good intersection of one of the distant points can be had, he determines its position by observation and intersection. Thus the operations of sketching the details close at hand, and the hill features, and the fixing of distant points are carried on simultaneously.

The great advantage of the use of *reference points* is now made evident. Having made note of several of these on beginning the sketch, one can, with his clinometer, place himself on a contour at any time and sketch the feature on which he may be with the knowledge that its contours can be joined with truth to those of adjoining features.

This system must, however, be followed with great care and judgment, as there is no means of checking the accuracy of the work in the first operations, and any error will be carried on and will enter all subsequent work. But, if the first part be carefully executed, a number of useful points can be obtained by reference to which, later on, the accuracy may be checked.

As a matter of economy of time, *one must learn to distinguish between the relative importance of different objects, and to devote proportionate time and attention to them.* In fact, this is essential in all kinds of topographic work.

Time may be so limited that all possible in the way of hill-sketching would be the indication by a few touches of the general position of the principal features. By means of these indications and a good memory, one should be able to produce a faithful representation of his recollection of the ground, its steepness being graphically shown by the contours being placed according to the scale of horizontal equivalents, which should be drawn on the sketch.

The sketch should be drawn with a hard lead pencil, to avoid obliterating any of the details when applying the shading. An eraser must not be used on the sketch if the paper is damp or wet.

LANDSCAPE SKETCHING.—A landscape sketch may sometimes be the only means of showing a portion of ground of which the sketcher succeeds in getting a view, though he cannot, as when it is occupied by an enemy, attempt measurements or observations of any kind. In such sketches prominence should be given to such objects as are likely to play an important part in an attack or defense, as villages, farms, roads, streams, artillery positions, etc. The sketch should be as much in outline as possible, with nothing exaggerated or misplaced.

The point of the compass from which the landscape sketch of an object was made should be stated, as also the estimated distance.

The ability to make a good landscape sketch is a natural talent, but something may be learned of it with a few simple aids:

1. To obtain an idea of the relative sizes and perspective of objects, as seen from a certain point, get a photographic negative from there. From the negative make *a blue print*, take the blue print to the point, and with a lead pencil trace the outlines on the blue print just as if you were making an original sketch on a clean sheet of paper, constantly referring to the landscape to get the connection between it as seen and as it appears on the blue print and as traced. Having traced all the outlines, etc., on the blue print, put it in a weak solution of ammonia and fade out all the color, then wash in clear water, and there will remain only the pencil outline on the white paper.

2. Another aid to learning is to flow a *pane of window glass* with photographer's transparent negative varnish, or other preparation, to produce a surface upon which pencil lines may be drawn. Fix the pane of glass in a vertical position, and, placing the head behind it at such a point as to get a view, through the glass, of the landscape to be sketched, proceed to draw in the outlines in pencil on the varnished surface, being careful not to move the head from its position until the sketch is completed.

3. Another aid is to take an *ordinary picture frame*, stretch fine threads across, forming suitable size squares, and fix it in a vertical position in front of one. On a sheet of paper similarly divided into squares, locate and sketch objects as seen in the different squares in the frame, being careful, when locating the objects, to always have the eye at the same point in front of the frame.

4. As one becomes more proficient he may dispense with these and sketch *directly on his paper*, at first, perhaps, drawing a horizontal line across his paper, to represent his visible horizon, at the relative height on the sketch that it occupies in the landscape, and through the middle of this horizon line drawing a vertical line. Then looking intently for a short time at an object centrally located, and without moving the head, suddenly raise the paper in a vertical position in front of the eye, the horizon line coinciding with the visible horizon, the vertical line through the object, and mark the position of the object on the vertical line. Other points in the field are similarly marked, always holding the sheet in the same position with the first point marked covering the central object each time, and at the same distance from the eye. After a sufficient number of points have been thus located, the intermediate points may be filled in by the eye. For this, distances may be measured from located objects, on the pencil held at the distance from the eye that the paper was held.

Marginal sketches. It has always been an admitted advantage if a good pictorial representation of ground could be made in addition to mapping it. And small free-hand sketches may be made on the margin of maps opposite the objects they represent, to illustrate the description of such objects. These might be of *bridges*, or a *gate* where a trail leads to a ford, etc. Such sketches enable one to recognize the point at once, when its identification by means of the map might cause delay. Or the distant view of a remarkable clump of trees, church spire, or other object might assist the superior officer in recognizing the locality on his arrival. There

should always be a good reason, however, for adding such sketches to a map, other than their pictorial effect or to show the skill of the sketcher.

The use of hand cameras is advocated for these purposes, and while it does not yet possess the rapidity so essential to reproducing views at once, it is rapidly advancing towards such a state, and much valuable information will probably be obtained in the future from the use of photography in the field.

COMBINED SURVEYS.—*I. In case of a very large tract, which has not been previously mapped, when time and instruments are available for accurate work*, the operations may be carried on by a number of parties simultaneously.

Control Points. A number of control points, consisting of conspicuous and easily recognized objects or targets throughout the tract, are located by primary triangulation. These are then carefully plotted on one large sheet for the basis of the survey, and by this means the general accuracy of the map is secured, independent of the minor errors that may be made in the component surveys, executed with less accurate instruments.

The tract is then divided into parts, bounded by prominent features, natural limits, or by established lines. The triangulation points contained in each part are "pricked off" on a field sheet and the calculated distances and directions of the lines between the points recorded on it. These field sheets are then given to different surveyors.

These control points should be so situated as to have at least two or three in each part, thus obtaining one well-established reference line. From these control points, the positions of interior points will be obtained by secondary triangulation. Triangulation points beyond the actual limits of his portion may also be given to each surveyor, by means of which he may determine interior points either by resection, triangulation, or by intersection.

Filling in. The details of the ground are then *filled in* by some of the methods already explained.

Each surveyor sketches the *hill features* in contours at the same contour interval, but not necessarily from the same level. In a combined survey for military purposes, all that is necessary is, that the shapes and slopes of the features should be correctly represented in each portion, which can be done without the contours meeting. To make them do so would be difficult to arrange, and the temptation to make them meet when correcting the margins should be avoided. The details of roads, rivers, etc., should meet accurately.

Should a magnetic compass be used in "filling in," each surveyor will determine its declination from an observation on the line joining the triangulation points, so as to lay down a magnetic meridian on his portion, in its proper relation to these points.

Finishing the sheets. When finishing up the sheets in ink, a margin of half an inch around each is left in pencil. The work of the best surveyors will not always agree where roads, fences, streams, etc., cross their mutual boundaries; hence a certain amount of alteration will be required in these parts. These alterations will be made in pencil while both sheets are adjusted, side by side, on the general triangulation sheet, *by means of the given control points.*

The application of lead shading is peculiarly suited for producing uniformity in a combined survey. After all are joined, a little blending of the margins only is required.

Each surveyor will be instructed as to the size and style of lettering and coloring to be used.

The officer, charged with the whole, distributes the work and combines the surveys. If he has a number of officers assisting him, he may divide the tract into groups, of three or four parts each, giving to each officer tracings of the original triangulation of his group.

Grouping the sheets. When the field sheets of a group are finished, except the margins in pencil, the officer in charge of the group adjusts them *by means of the given triangulation points,* fastens them down firmly on a table with pins along

their mutual borders. With a sharp knife held vertically, he cuts through both sheets at one cut, which will be made close along the boundaries, so as to leave the road, river, or whatever it may be, in one survey only. The necessary alterations are then made in pencil, the sheets separated and afterwards inked, except around the outer edges of the group. The sheets of the group are then again adjusted and joined by narrow strips of paper pasted on the back. The different groups as thus completed are, by the officer in charge of the whole, then adjusted beside each other on the general triangulation sheet. The group sheets are pinned down, cut through, the alterations made in pencil, separated and inked, and afterwards adjusted and fastened together.

Should there be any large discrepancies in the margins of adjoining surveys, the error should be discovered and corrected on the ground.

II. If a map of the tract is at hand, and it is desired to resurvey it for the purpose of showing its tactical capabilities and recent alterations, but neither time nor means to triangulate it are available, different methods would be adopted.

The officer in charge would cut out from the map the groups into which the tract is to be divided, and hand them over to the officers in charge of the groups, who further subdivide them into parts bounded as much as possible by roads, streams, etc.

Each surveyor fastens his portion of the map on his sketching-board, and studies the general map so as to recognize the limits of his part, and to impress on his memory the relation of his part to the whole, and the direction and position of rivers, water-sheds, etc.

Each should also draw on his part a magnetic meridian, so he may recognize its relation to his work done with the compass. He should also determine the declination of his compass so as to put a true meridian on his part.

The parts being finished as before, they are adjusted by the officers in charge of groups, by means of the true or mag-

netic meridians being made parallel, with the north points in the same direction. The chief difficulty in combining them is, that errors cannot be at once noticed and traced to the part in which they exist, as in the case where the tract is triangulated.

Even with the best surveyors, the errors and failures in meeting will generally be considerable, and much judgment is required in the arrangement and execution, and in combining them. After the parts are adjusted, they are cut, corrected, etc., as explained above.

III. When triangulation is impracticable and no map is available, a general route or road through the entire tract is selected to form the boundary between the sketches made on both sides of it (Fig. 215), the outer boundary being the limits of the tract. The compass bearing of a line perpendicular, or nearly so, to the general direction of the road, is selected as the lateral boundary of each part, and each surveyor takes the reading of his own compass on this line.

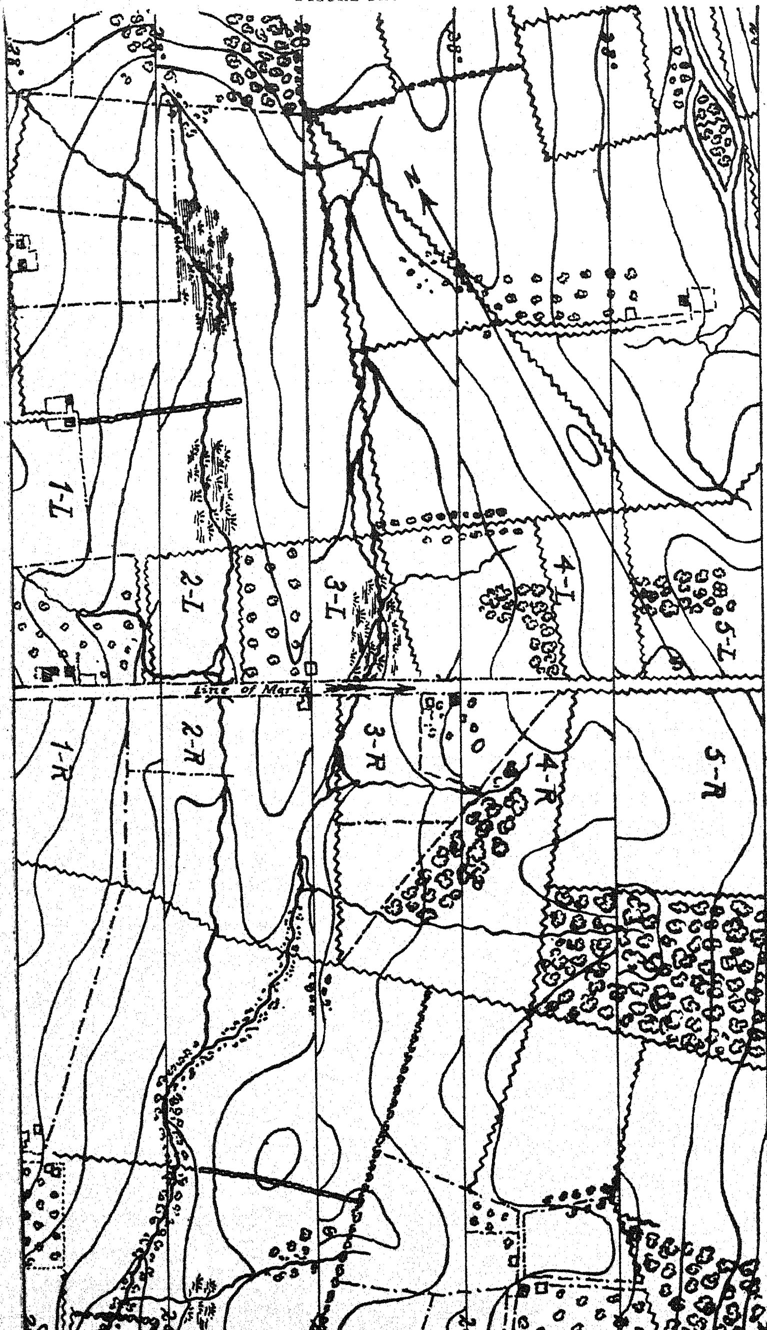
The tract is then divided along the road into parts of as nearly equal width as possible, the points of division being marked by conspicuous natural or artificial objects, and each part on the right and left assigned to a surveyor.

The officer in charge will walk along the road with the surveyors and leave two at each point of division, one to sketch on the right and the other on the left of the road.

On being shown the limits of his part of the tract, as marked on the road, each surveyor will find by trial an object in the distance having the direction of the dividing line as shown by his compass, and will carefully traverse the line in this direction the entire distance to which his sketch is to be carried from the road.

Each one of a pair will be made especially responsible for the accuracy of *one* of his lateral boundaries, and for the accuracy of the road between them. Thus, if the road traversed the tract from west to east, the lateral boundaries being north and south, each might be made responsible for the western

FIGURE 215.



boundary of his part, and he will devote particular attention to this line and trust to the man east of him to traverse his eastern boundary accurately. In this way a much greater general accuracy may be obtained than if each were to employ his time in sketching every part of his ground with equal care. In combining the sketches, the necessary alterations are made only on the side of each on which the least care was bestowed.

CIVIL MAPS AS A BASIS FOR MILITARY TOPOGRAPHICAL MAPS.—Occasions will often arise, especially in a country like our own, where small-scale civil maps are quite common and military maps scarce, when the ability to use the civil map as a basis or control for a military map may be of the utmost importance. This result may be attained in various ways; one of the simplest, whose value has been tested, is as follows:

Preliminary work. Having secured the best civil map (county, state, coast, or geological survey) that is attainable of the tract of country desired, enlarge it on tracing-cloth, by one of the methods described in Chapter XXI., to $\frac{1}{2}$ inch or 1 inch to the mile, showing, as in the original, roads, streams, towns, railroads, school-houses, churches, etc. Make two nigrosine (or any other black-and-white process) copies from this tracing and mount them on cardboard. Draw meridians about 3 inches apart across one of these mounted maps and then cut it into rectangles of a size convenient for carrying. (In doing this, care should be exercised in order that as long stretches of road as possible may be left on the small sheets.)

Field work. Having selected from among the small sheets those showing the routes for the day, the sketcher, either on horseback, on a bicycle, or in a vehicle, travels over the roads, making constant comparison of the terrain with his map. He records no distances and takes no compass directions, except such as may be necessary to orient his map or locate his position on it; he *jots down* in black pencil on his skeleton map, after estimation of distances and directions, all details of military importance, such as the location and extent of forests,

new roads and railroads, telegraph lines, new bridges, schoolhouses, churches; *obliterates* from his sketch such features as have ceased to exist, and *changes* such as he finds to be wrong.

While accurate contouring will usually be impracticable, the general configuration of the terrain should be shown by form lines, as in road-sketching.

A brief *road report* would also be of value.

Finishing the map. On returning at night, a fair copy of the field notes taken during the day is made in colored pencil or colored inks upon the uncut skeleton map, while important data from the road reports is embodied in a legend.

The process outlined is perfectly applicable to a *combined survey,* although in this case the fair copy from all the field sheets should be made by one person. The fair copy, in both cases, may be made by any draughtsman, while skill and judgment are prime requisites to the sketcher in the field work. A good sketcher can, if necessary, fill in from 30 to 40 miles of road in a day.

CHAPTER XXIII.

MAP-PLOTTING FROM DÀTA.

It will often happen, owing to lack of time or to inclement weather, that a sketcher can make but few notes. This data, if judiciously taken, may be the basis of a good map.

Cases may arise where one topographer will have to translate and plot the notes of another. In such a case, if the notes have been clearly and legibly written, a useful map may be produced. To do this, the topographer must understand the meaning and significance of the various terms employed, and be able to express them by conventional signs.

The construction of maps from data is also an important aid in learning map-reading.

As an example of the foregoing, let it be required to make a contoured plot from the following data:

Problem 1: The pickets of an outpost occupy a ridge whose general direction has a bearing of 120° with a *prismatic compass* graduated thus:

180
N
90 270
S
0

The enemy is in a direction bearing 20°.

The ridge has two prominent hill-tops, A and B, with a col between them. Hill-top A is the more northerly.

Parallel to the ridge and 2,000 feet in rear of it flows a stream for 1,500 yards, where it empties into a lake.

The head of the stream is on a level with the top of a 60-foot pine standing on the bank of the lake into which the stream flows.

From the point A the following observations are made:

Bearing of head of stream, 256°;
Vertical angle to head of stream, —2°;
Slope uniform;

and from B the following are made:

Bearing of mouth of stream, 200°;
Vertical angle to mouth of stream, —4°;
Slope uniform.

Ridge terminates in an abrupt cliff 500 feet beyond B.

The col is midway between A and B and 76 feet below A. From the col the slope toward the stream is slightly concave and heavily wooded.

The lake is assumed as datum.

Scale to be 1 inch=1,000 feet. Contour interval 20 feet.

Problem 2: A stream winds through a valley in a direction bearing 215 degrees for a distance of 1,000 yards. Its average fall is $\frac{1}{30}$.

From the head of the stream, with a *box compass* graduated thus:

0
N
90 270
S
180

The bearing of A is 245 degrees, the angle of elevation 4 degrees, slope concave; and from the mouth of the stream it bears 357 degrees, the bearing of C being 60 degrees.

From A the bearing of C is 120 degrees.

From C the bearing of B is 33 degrees.

The angle of elevation of B from the head of the stream is 4 degrees.

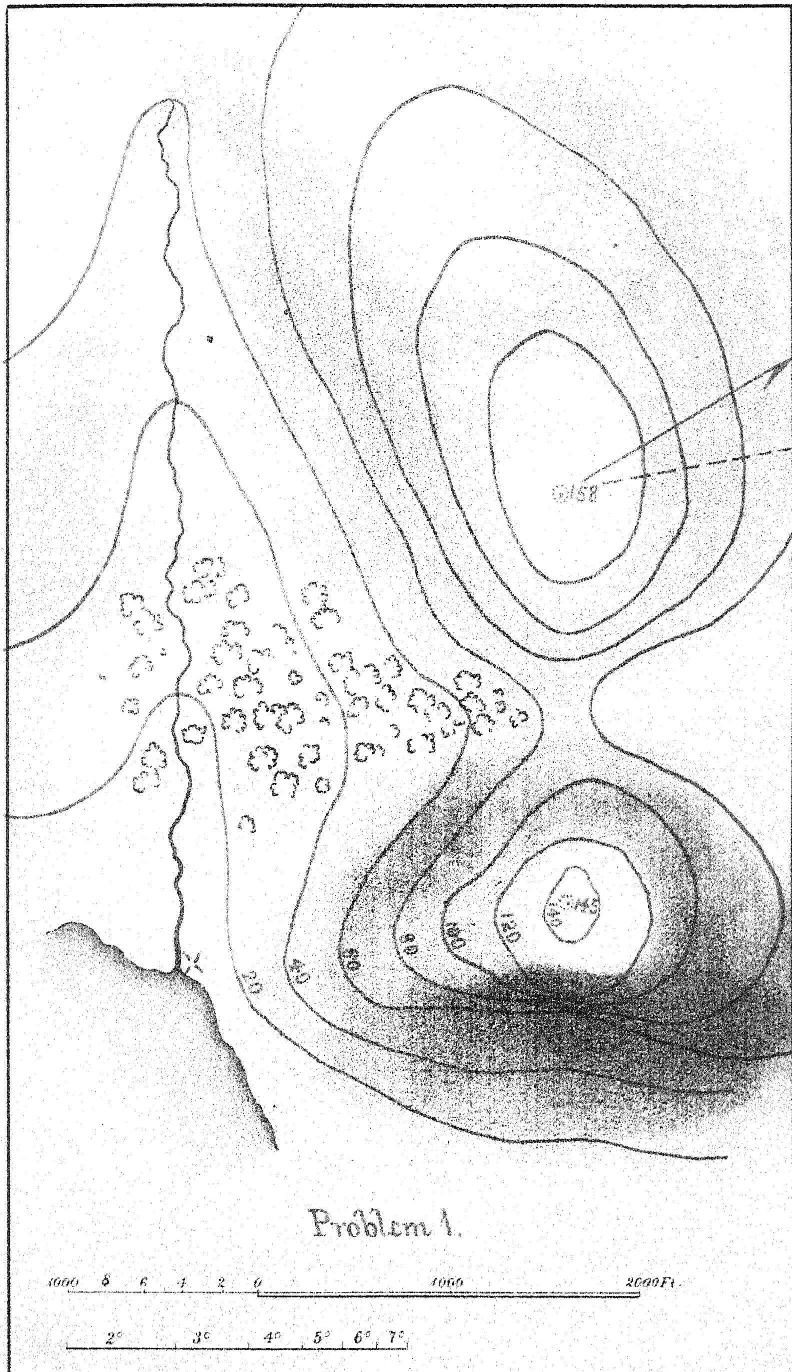
C and B are each 40 feet higher than the head of the stream.

The col between B and C is 55 feet above sea-level.

Required a contoured plot from the above data. Scale, 6 inches to 1 mile; contour interval, 20 feet.

Problem 3: A, B, and C are hill-tops overlooking a lake between them.

The bearing of this lake from A is 15 degrees, of B is



Problem 1.

135 degrees, and of C is 255 degrees, with a *prismatic compass* graduated thus:

180
N
90 270
S
0

The hills A, B, and C are respectively 70 feet, 130 feet, and 90 feet above datum level, the lake being 30 feet above it.

The clinometer shows the slope to A, B, and C to be $1\frac{1}{2}$ degrees, 4 degrees, and 2 degrees, respectively.

Required a contoured plot from the above data. Scale 6 inches to 1 mile; contour interval, 20 feet.

CHAPTER XXIV.

MILITARY RECONNAISSANCE.

Military reconnaissance is the process of obtaining information of a military character; 1st, *about the enemy*, his movements, numbers, dispositions, etc.; 2d, *about the country for tactical purposes*, as its nature and resources, its communications and facilities for the movements of troops, etc.

Reconnaissance of the *enemy* is a subject of Security and Information. Reconnaissance of the *country* belongs to both Topography and Tactics.

As indicated in Chapter I., though existing maps may be available, it may be necessary, in order to make them useful for military purposes, to supplement or correct the information contained in them by a *topographic reconnaissance*.

This will usually consist of two parts, *the sketch*, and a *written report or description* accompanying it, giving details which could not be shown on the sketch without crowding or confusing it. Complete information can be given only by the two together.

Time is, as a general rule, limited, even if the difficulty is not still further increased by the actual presence of the enemy. Hence, rapidity and accuracy in sketching and in taking notes are indispensable, as well as coolness and good judgment. The order for the reconnaissance will indicate its object, the extent of country to be embraced, the time allowed, together with any special instructions, which will be the guide as to the nature and amount of details to be sketched and described, and the objects to which particular attention is to be paid.

THE SKETCH.—The sketch should contain all that can be shown without crowding or confusion; remarks being made in the margin, clear of the sketch, and connected with the object to which they refer by a light line.

Drawing. The minimum of drawing is done in the field, the sketch being afterwards finished up as highly as time permits.

Details. The smaller the scale, the fewer details can be shown, time being wasted in trying to show too much.

Towns. On very small scales, in representing towns, it is only necessary to distinguish the largest and most important buildings, to show the side streets correctly, and afterwards fill up the remainder with the conventional signs for buildings, grouping them to conform to the general shape of the towns.

Roads. While roads, etc., cannot be represented at their proper width on small scales, being shown in the field by a single line, they should be drawn about $\frac{1}{20}$ of an inch wide.

Fences. In a fenced country, it is allowable to generalize details of fences in the less important parts, and simply represent enclosed fields of the average size, according to scale.

Distant places. Lines may be drawn from different points in the direction of important places some miles distant, their names being written on these lines, the intersections of which fix the places indirection and distance.

Lie of the country. Attention must be paid not only to what is near, but also to the general lie of the country, to prominent distant features, etc. The positions of streams may be recognized by trees growing along the banks.

Heading sketch. The sketch should be headed, signed, and dated on the face, by the officer making it.

THE REPORT.—*Reference numbers.* Before commencing to write the report, every place on the sketch to which reference will be made in the report, except names given on sketch,

should be marked with a colored numeral and surrounded by a circle, beginning at the bottom and numbered consecutively to the top, for the purpose of identification.

Writing report. The rule in writing reports is to make it legible and not to repeat what is already given in the sketch.

Names of places. Names of places should be written phonetically, as pronounced by the inhabitants, in addition to their spelling as given on the maps of the country.

Information. Only relevant and thoroughly tested information should be given. The sources of all other must be stated, as hearsay, or estimated, etc., if reported. Reports should be governed solely by the object of the reconnaissance, as information relevant in one case might be useless in another. In framing reports, the ability and judgment of an officer are shown as much in what he omits as in what he writes. It requires more thought and care to compose terse and well-condensed than lengthy, diffuse reports.

Terms used. General terms, such as large, small, wide, narrow, etc., should not be used, but instead the exact numbers and dimensions should be given. The terms *north*, *south*, etc., should be used instead of *right* and *left*, except in case of streams, where the *right bank* and *left bank* are always considered to be those on the right and left hand of the observer when facing down stream.

Orders. A copy of the order and instructions in accordance with which the reconnaissance was made should always be attached on the last page of the report. These may exonerate the officer from blame if circumstances should materially change during the execution of the reconnaissance, or from what was supposed to exist when the order was issued.

Briefing and attaching report. The report should be briefed, signed, and dated, the same as the sketch, by the officer making it, so that if it becomes detached they may be rejoined. The report is attached to the right edge of the

sketch by a strip of mucilaged paper on the back, with the bottom edges of the two even. If the sketch is longer than the height of the report sheet, the sketch is first folded over even with the top of the report and then the whole folded to official size; the last page of the report being the first page of the whole.

Blank forms. A form for the report, for each kind of information, will usually be furnished, giving the headings of each branch, and in some cases a summary of the details embraced by the headings. Only those headings would be reported which come under the object of the reconnaissance.

RECONNAISSANCE OF A ROAD.—Reconnaissances of roads are usually made with a view to the movement of troops over them, hence precede such movements by one or more days. The work is usually done on horseback. If in an enemy's country, the reconnoiterer is accompanied by an escort of cavalry for protection and to seek additional information.

The object of the reconnoiterer is to produce a sketch of the route by which the troops may move, reporting on the general nature of the country, with the difficulties to be met with in marching, etc.

The sketch. This is made on a *scale* of about 1, 2, or 3 inches to a mile, using either horses' paces or a time scale for distances. A graphical scale of miles, yards, or feet and a magnetic meridian must always be constructed on the sketch be-ore handing in.

The *sketch is begun* at the bottom of the paper and carried upwards in the order of march, and is in the nature of a traverse either with compass, field sketching-case, or without instruments. When the sketch will take the form of a long, narrow strip, *the meridian lines* must be arranged diagonally, if necessary, so the road may occupy the central line of the sheet.

The sketcher seldom leaves the *main road*, except to go down a cross-road a short distance to examine a bridge or

ford by which it crosses a stream, or to a near hill-top to get a distant view, etc.

The *adjacent country*, as far as visible from the road, about $\frac{1}{2}$ or $\frac{3}{4}$ of a mile to the right and left, should be sketched in.

The *general direction* of cross-roads is merely referred to the traversed road, except where seen for some distance, when their direction may be observed.

In sketching a *winding road* (unless using the field sketching-case), it will generally be sufficient to take the bearing of the long reaches, sketching in the intermediate portions by eye.

Details are sketched in by offsets, as already explained.

Hill features, the grades on the road, etc., are shown by *form lines*, no attempt being made to make the contours of adjacent features join and be continuous, or to refer them to a common datum. The slopes are read with the clinometer, or, after practice, simply estimated.

All *commanding ground* within artillery range should be located by intersection.

Free-hand sketches may be used as explained.

The report. The information required about the road may be either *tactical* (relating to maneuvering capabilities) or *statistical* (relating to the population, supplies, accommodations, etc.).

Both kinds of information might be required at the same time of a single officer and embodied in one report, but it is usual to separate them and assign only one to a single officer.

The tactical information most usually required is here classified.

HEADINGS.	SUMMARY.	EXPLANATIONS AND REMARKS.
I. THE ROADWAY.	*Construction.*	Whether macadam, corduroy, plank, gravel, clay, or earth. Whether worked or formed by traffic.
	Width.	Of the roadway proper. 9 feet is the minimum for infantry in fours, cavalry in twos, wagons or guns in column; 16 feet for a double column, or to permit passing.
	Condition.	First its *present* condition, then whether rains would affect it and how; whether any other circumstances might alter its condition, such as soil, nature of drainage, adjacent ground, etc. The length of any bad parts should be stated, and the way of avoiding them, if possible.
	Materials for repair.	Such as piles of stones on the roadside, loose stones from near quarries, gravel, timber, or brushwood for fascines, etc.
	Grades.	On hilly roads with a grade steeper than 3°, or $\frac{1}{20}$, the slope should be stated. For short distances artillery can go up 15°, or about $\frac{1}{4}$; heavy wagons 8°, or about $\frac{1}{7}$; for steeper grades extra horses must be attached.
	Defiles.	Any narrow part, as the street of a village, a cutting, etc., together with its length, width, and height of sides, and whether it can be widened, or the sides accessible, etc.
	Fences.	If on the sides of a road, the kind, as stone, hedge, board, picket, wire, rail, etc., and the distance between them. Whether they are an obstacle to movement or afford cover from fire.
II. BRIDGES	*Variety.*	Whether a draw, swing, suspension, cantilever, trestle, truss, arch, ordinary or foot-bridge, etc., in detail. If an arch, number of, whether elliptical, semi-circular, or segmental. The *span* is the horizontal distance from pier to pier. Whether strong enough to bear guns. Bridges of small span, easily demolished or repaired, need not be so minutely described.

	Material.	Whether of steel, iron, wood, stone, or brick, or a combination of several.
	Length, breadth, and height above water.	Length of bridge, length of approaches, breadth between wing walls. If bridge passes over the road, the clear height above the road should be given.
	Piers.	Describe in detail as to material, thickness, number, distance apart.
	Fords near.	State exact position; the length and breadth; ordinary depth; nature of bottom; whether liable to shift or deepen; velocity of current; means of destroying or repairing; condition of approaches, roads, or paths. See *Fords* in Reconnaissance of Rivers.
III. RATE OF MARCH.	*Anything that might retard the usual marching rate.*	Such as steep grades, rocky places, deep mire, heavy sands, etc. In every case the probable rate of marching to be given.
IV. TOWNS AND VILLAGES.	*Description.*	Whether *salient* (extending lengthwise of road), *broadside* (extending across the road to right and left), or *circular*. Farms of importance under this head.
	Construction.	Material of the houses, inflammable or not.
	Streets.	Whether paved (giving kinds, condition, etc.) or not. Breadth, straight or tortuous, etc.
	Enclosures.	Kinds of, whether gardens, orchards, etc., and walls or fences by which surrounded.
	Principal buildings.	Such as churches, manufactories, public buildings, large dwellings, telegraph and telephone offices, etc. Size of each; whether suitable for barracks, hospitals, etc. Position of each, if not shown on sketch, with reference to approaches.
	Defensibility.	Whether commanded from neighboring heights; materials for barricading and making abattis; whether tools for entrenching are available in any quantity.
V. COUNTRY.	*General description.*	Of what is not shown on sketch. Anything that limits the view, etc., as woods, nature of them, impassable or not.

	Nature of soil and cultivation.	Whether rocky, sandy, clayey, marshy, etc. Character of cultivation, direction of rows of high crops, as corn, vineyards, etc., kinds of fences by which covered.
	Practicability for different arms.	Whether movement across country or parallel to the road would be possible for any or all arms.
VI. RIVERS, STREAMS OR CANALS.	*Width. Depth. Velocity. Bottom. Banks. Fords. Locks. Inclined planes. Aqueducts.*	The summary here given applies only to the points where the road crosses a river, stream, or canal. Of the banks, the command of one over the other would be given. Important rivers would usually be separately reconnoitered. See Reconnaissance of Rivers.
VII. HALTING-PLACES.	*Extent. Proximity of water.*	The amount of space, the amount and kind of drinking water, for men and animals, are the chief points. Whether part of command could pass from rear to front, etc.
VIII. CAMPING-GROUNDS.	*Force for which available. Water, wood, grass, etc.*	This only when required by orders.
IX. POSITIONS.	*On or near road for advance or rear guard.*	According to special instructions.
	Any favorable for enemy from which he could observe road.	Enemy's position reported on as seen from road.
X. LATERAL COMMUNICATIONS.	*Construction, width, condition, etc.* See I.	These relate to roads or trails crossing or joining the road being reconnoitered.
XI. RAILROADS	*Gauge. Single or double track.*	Also, name if attainable, and to and from where it runs. Stores and rolling stock available.
XII. TELEGRAPH LINES.	*Number of wires. Kind of poles.*	The connecting points if obtainable.

The statistical information desired would relate almost exclusively to supplies, accommodation, and population, and would probably be entirely a written report on a form prepared for that purpose.

I. In the first column would be the name of the place reported on; or, in case the sketch was made, its reference number. The order of reference numbers and names should be the same as on the sketch—that is, the highest number or most distant place would first be described at top of report, the starting-point at the bottom.

II. Distances from starting-point and from place to place are both reported, unless the report accompanies a sketch, when they may be omitted.

III. The number of houses and the population may generally be obtained from the corporate authorities. If not, the number of houses may be approximated by estimating the number in each street from the estimated length of street and the average size and compactness of the houses on each.

The population may be estimated at an average of about 5 to every house.

IV. In estimating the accommodation, one man per yard of front of the house may be allowed if only one room deep, two men per yard of front if two rooms deep, etc. If house has more than one story, multiply by number of stories high, less one for the family. If estimated by rooms separately, one man per yard of length may be allowed if not over 15 feet wide, two men per yard of length if between 15 and 25 feet wide, 3 men per yard if width exceeds 25 feet. These would be only temporary accommodations.

If all houses could not be calculated as above, then they might be divided into classes according to size, and a house of each class examined and the accommodation estimated, from which that of the entire place could be obtained.

In estimating the accommodation of barns and sheds for horses, if desired, one horse per 5 feet of length may be allowed if not over 24 feet wide, and two horses per 5 feet of length if over 24 feet.

V. Under supplies, the names of persons from whom they may be obtained are reported; also the number of grocery stores, butcher shops, blacksmith shops, hotels, and any other places where edibles and drinkables are to be obtained.

VI. Under transportation, the names of persons from whom wagons, horses, etc., can be obtained are reported; also the number and kind obtainable from each.

VII. Under water would be stated whether drinking water is obtainable from reservoirs, cisterns, wells, springs, etc.; the amount and quality; also water supply for animals.

To calculate the supply obtainable from a small stream, multiply together the mean depth, width, and velocity per minute, all in feet, for the cubic feet per minute. To reduce cubic feet into gallons of 231 cubic inches, multiply by 7.5.

In permanent camps men require at least 5 gallons each per day and horses 10 gallons.

RECONNAISSANCE OF RAILROADS.—Railroads play an important part in modern warfare. By their means troops and supplies are transported with rapidity from one point to another. Railway centers and junctions become important strategic points. In the reconnaissance of a railroad, if a sketch were required, it would be made upon the same principles as the sketch of an ordinary road, but would also include plans on a larger scale of the important centers and yards. On these plans each pair of tracks would be shown by a single thick line.

The report would be divided into two parts: *1st, The Line; 2d, The Stations,* and the information under each about as follows:

1st. The Line.

1. The names of places through which it passes, and other lines with which it connects.
2. The general character of the country through which it passes.
3. Whether single or double track; gauge in feet and inches (4 feet $8\frac{1}{2}$ inches standard gauge), and general condition.
4. Description of rails, whether iron or steel; weight per yard; how laid, on chairs, tie-plates or not; how fastened, by fish-plates, angle-irons, etc.
5. Description of ties, material, distance apart, whether laid on ballast (kind) or not.
6. Description of bridges, kind, material, length of spans; best method of destroying, etc.
7. Locations and lengths of sidings, and if there are conveniences for loading and unloading troops, animals, and supplies.
8. Gradients, cuttings, embankments, viaducts, tunnels.
9. Practicability of marching troops along the line.
10. Places, other than at sidings or stations, where troops could be loaded or unloaded.

2d. Stations.

1. General description as to size, material of which built, whether situated on the level, on an embankment, or in a cutting, and whether adapted to defense.
2. Description of freight-houses, round-houses, and other buildings.
3. The number of cross or junction lines.
4. The lengths and breadths of platforms, facilities for erecting temporary ones.
5. Direction of approaches and widths of entrances to the station.

6. Space outside where troops could be formed and for camping in vicinity.
7. Supply of water for engines, and for troops and animals.
8. Amount of rolling stock, locomotives, and cars of different kinds and capacity.
9. Stores of different kinds, as rails, ties, fuel.
10. Number of telegraph lines, location of batteries and materials for repair.

RECONNAISSANCE OF RIVERS.—The object of the reconnaissance of a river is generally for the purpose of ascertaining how it may be crossed by an army, or to oppose the crossing of it by an enemy.

The sket h. This must usually be made on foot, and generally on a scale of about 2 or 3 inches to a mile.

If the river can be followed on either bank, it would be sketched by traversing, points on the opposite bank being fixed by intersections or offsets.

The sketch should include as much of the country as can be seen from the banks; and towns, woods close to it, roads and trails leading to it, and all commanding heights within artillery range, should be carefully shown.

It will seldom happen that the same bank can be followed for the whole length, so the officer must be accompanied by a boat, to enable him to cross, and traverse on the other bank when necessary.

The report. If the river is *parallel to the general line* of operations, it would be reconnoitered with a view to showing how connection could be maintained between columns on both banks, either during the march or for action. Such a river is the best protection from an enemy's enterprise on a flank, as it is only necessary to seize the boats and guard the bridges and fords to secure it.

The information in such a case would be as follows:

HEADINGS.	SUMMARY.	EXPLANATIONS AND REMARKS.
I. THE VALLEY.	*General description.*	Whether broad or narrow; marshy, rocky, wooded; proximity of heights on one or both banks. Much the same information as under V. THE COUNTRY in road reports. As much of this to be given on sketch as possible.
II. THE STREAM.	*Navigable or not.*	Length of navigable portions; obstacles to navigation, to be given.
	Tidal or not.	
	Width.	
	Average depth.	The deepest parts in winding rivers will be found near the concave bank.
	Velocity.	Obtained by noting how many seconds it takes a floating object to go a certain number of feet. 0.7 the number of feet per second is approximately the number of miles per hour. The strongest current will usually be in the center of the river.
	Liability to overflows.	Learned from inquiries. Extent. Time of year of usual large rises.
	Bottom.	Whether rocky, gravelly, sandy, or muddy; whether even or irregular.
III. THE BANKS.	*Nature and heights.*	Whether precipitous, and if so, how high; marshy or not; lined with trees or not; what cover they afford; what facilities for crossing, or forming ramps to fords.
	Command.	Of one bank over the other, in feet.
	Towpaths.	
IV. TRIBUTARIES.		General description of each to be given.
V. ISLANDS.		Position; size; whether woody, marshy, cultivated, etc. Command over either bank; distance from, to banks.
VI. BRIDGES	*In detail.*	As given in road report.

VII. FORDS.	*In detail.*	As given in road report. Location may be ascertained by questioning; by roads or trails leading to it from either bank; often by houses near; by dropping down in boat with sounding line of required length attached, when weight touches bottom, a ford may be looked for. May be expected in parts where river widens, or obliquely across from one convex bank to another. Fords practicable for cavalry about 4 feet; infantry 3 feet; guns and wagons 2.5 feet.
	Other points.	Where crossing might be made practicable by military bridges or other means. Also if river freezes over to bear crossing, and for how long.
VIII. BOATS.	*In detail.*	Whether regular boats, ferries, or flying bridges, with full description as to kind, size, capacity, etc. Number of men that can be carried each trip and time required. Whether materials for rafts are near.
IX. LOCKS.	*In detail.*	Length; width; fall of water; time required to fill and empty; whether exposed to distant artillery fire. Position of, should be shown on sketch.

If the river is *perpendicular to the general line* of operations, it is necessary to concentrate at one or more points, in order to cross, and to deceive the enemy as to one's real intentions. In which case it might be used as a defensive obstacle, and the report would contain, in addition to the above, the following information:

X. APPROACHES.	*Nature of.*	And points at which access by them may be barred by troops or obstacles.
XI. HEIGHTS.	*Command and distance.*	On either bank within artillery range.
XII. INUNDATIONS.	*Points and means of effecting.*	
XIII. POINTS SUITABLE FOR COVERING PASSAGE OF TROOPS TO OPPOSITE BANK.	*Straight, reentrant or salient.*	

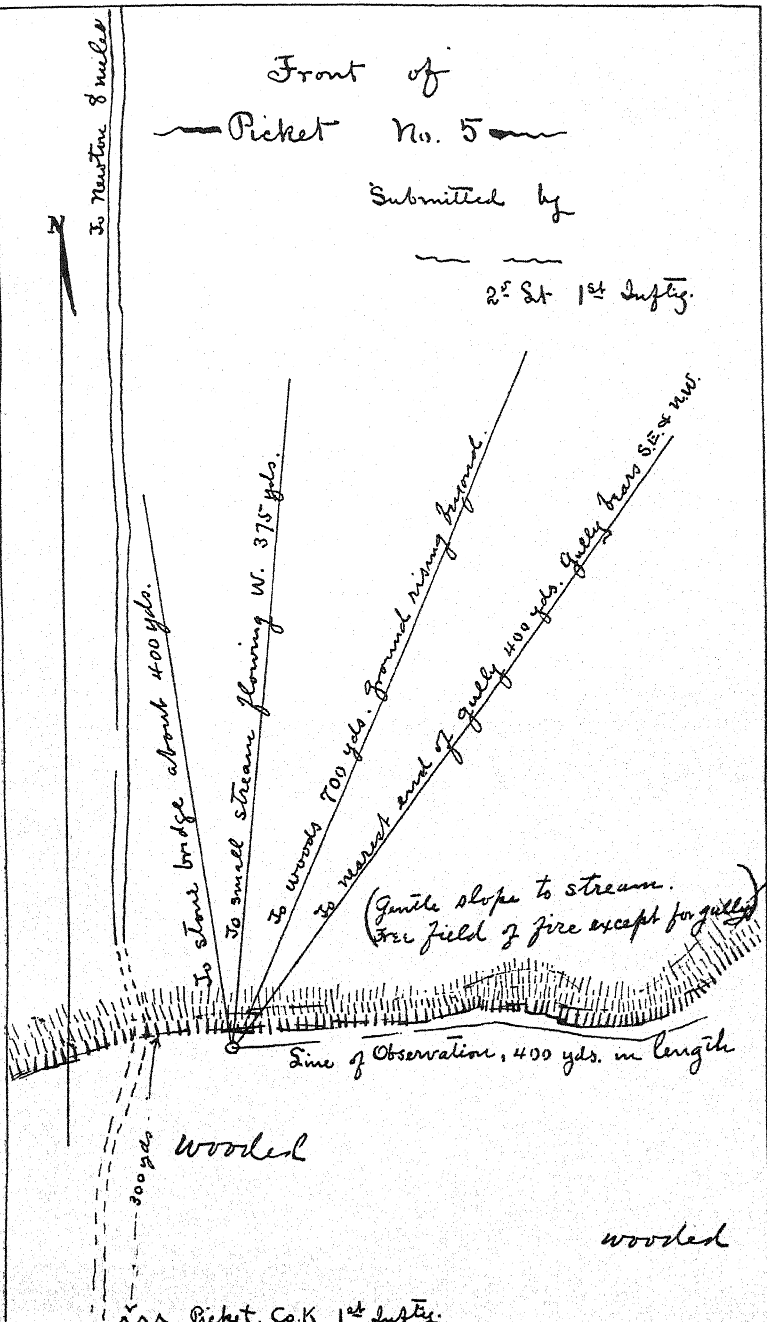
RECONNAISSANCE OF OUTPOSTS.—An officer commanding an outpost will naturally avail himself of the readiest means at hand of becoming familiar with the ground in his own immediate front. He will, of course, ride along the line of sentries or videttes to make personal observations, and take mental note of the steepness of slopes, the depth and direction of gullies, the location of impassable obstacles, and, above all, the position of roads over which the enemy may advance. To impress this on his mind and to have a means at hand for refreshing his memory, he may direct the commander of each picket to submit a sketch of the ground in his own front. As a rule, it may be assumed that the sketcher will find it impracticable to traverse the ground he is to sketch; in other words, that the line of sentinels or videttes will be the base from which the ground in front must be plotted.

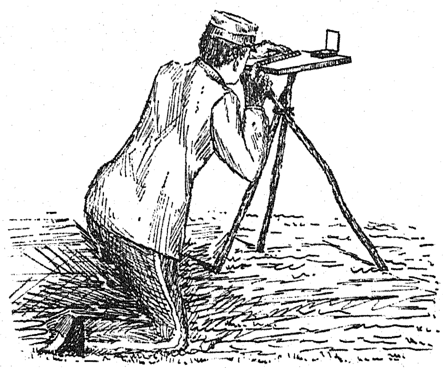
The sketch. There are two methods of doing this work.

1st method: This, while it hardly merits the title of a sketch, is shown below and consists merely in drawing radiating lines from some prominent point on the line of observation toward the various points to which reference is to be made, and then writing such data as may be necessary along these lines. (See figure). Telemeters are valuable aids in this work, although a ruler and pencil are the only instruments absolutely necessary.

2d method: The only other way of making the sketch where circumstances forbid traversing, is to measure as accurately as possible (usually by pacing) a base-line along the front, and then, using an ordinary drawing-board or box-lid as a plane table, locate the points in front by intersection. The instruments required in this class of work are a box compass, a ruler, and a clinometer or slope board. It has been found in practice that, while not absolutely essential, an improvised tripod, made by lashing three sticks together as shown, is of material assistance in securing rapidity and accuracy. The successive steps in this work are as follows:

Construct a scale of yards, of horizontal equivalents and

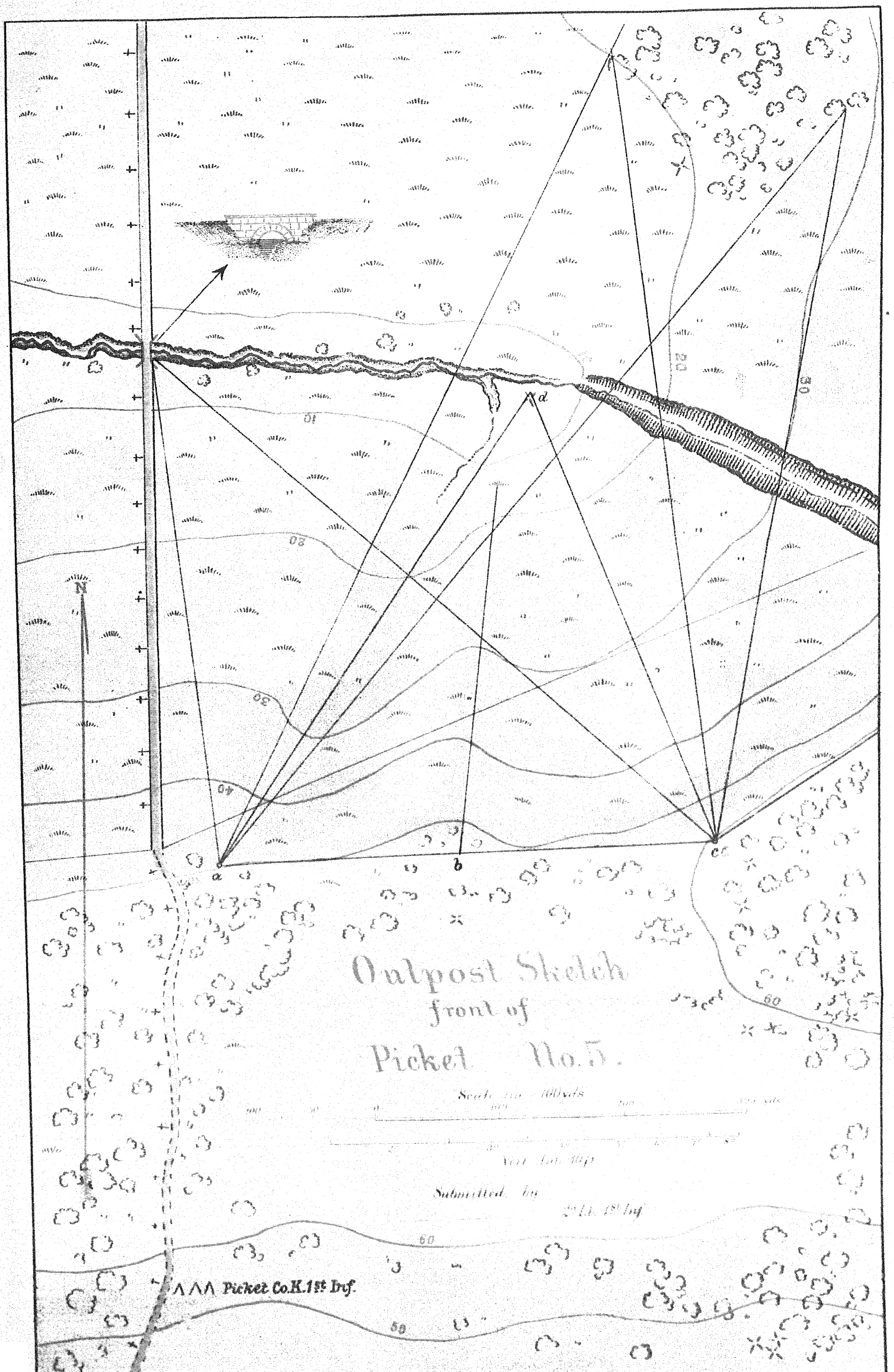

Front of
Picket No. 5
Submitted by
2d Lt 1st Infty.
N
To Newton 8 miles
To stone bridge about 400 yds.
To small stream flowing W. 375 yds.
To woods 700 yds. Ground rising beyond.
To nearest end of gully 400 yds. Gully bears S.E. & N.W.
(Gentle slope to stream.
Free field of fire except for gully)
Line of Observation, 400 yds. in length
300 yds.
wooded
wooded
Picket. Co. K 1st Infty.



of strides (the first two only should appear on the completed map) at such an R. F. that the map will be as large as the paper will allow (usually 6 inches to 1 mile, with a contour interval of 15 feet).

Select a base on or near the line of observation such that the important points to be plotted can be seen from the ends of the base, if possible. Go to one end of this base, and, having driven a pin into the board at the assumed origin, lay the ruler against it and draw an indefinite right line on the paper in the direction it is desired the base should lie. Revolve the board until this line points to the other end of the base; the board is now oriented and must not be moved until all sightings to be made at this point are completed.

Place the compass on the board and turn the former until the north end of the needle is at the N of the graduated circle; then draw a right line along the edge of the box and mark the north end of it. Pivot the ruler around the pin, and, sighting to prominent or important points, draw indefinite lines toward them, being careful to select definite points on which to sight; write along each line the point to which drawn. Refer to the compass occasionally to see that the sketch is still oriented. Pace to the other end of the base, and, after laying off its length to scale, and driving a pin into the plotted position of the other end, place the ruler against the two pins and orient by a back-sight, checking by the compass. Should the base be short, the orientation by the compass will be the more accurate. Pivoting the ruler around the second pin, take sightings on the same points that were observed from the first station; the intersections of the corresponding lines will



Outpost Sketch
front of
Picket No. 5.
Scale 1 in = 100 yds
Vert. Int. 10 ft
Submitted by
2d Lt. 1st Inf.
ΛΛΛ Picket Co. K. 1st Inf.
N
a
b
c
d
10
20
30
40
50
60

be the plotted positions of these points. Having thus located as many points as may be desired to fix the positions of roads, buildings, marshes, streams, gullies, etc., sketch them in by eye. Locate the important and the more distant points with the greatest care, slighting the "filling in" if any part must be slighted.

In regard to sketching in contours, it should be borne in mind that ridges and valleys *must* be located and their directions plotted before contouring is commenced. The readiest method of acquiring skill in this variety of contouring is to locate the prominent points of the sketch *first*, and then to go back to the initial point and begin contouring.

Assume, for example, in the map shown, that the important points, including a point *d* in the creek bottom and several reference points, have been located in the manner described (construction lines are left to show the method), and that the sketcher has returned to station *a*. He notices from this station that rather a prominent valley extends to the creek in the direction *ad*. This direction he plots, and, finding the general angle of depression to *d* to be 2°, he applies the horizontal equivalent for 2° as many times as it will go (in this instance four and something over, showing that the difference of level is between 40 and 50 feet). He further notes that the actual slope is 3° for about 150 yards from the top, and then more gentle the remainder of the distance. With this data, and having the ground itself to refer to, the contours crossing *ad* can be quite accurately sketched in for some distance to the right and left. Pacing along the base toward *c*, a ridge is encountered extending nearly to the creek. The sketcher stops, plots his position *b*, indicates on the map the general direction of the ridge, and then prolongs the contours already started, making them convex toward the creek, where they cross the ridge-line. Arriving at *c*, it is noticed that the line of sight of the clinometer used as a level cuts the lower branches of a tree near *a* at an estimated height of 12 feet; this shows *c* to be one contour higher than *a*, and it is drawn

accordingly. After a little practice, it is perfectly feasible to carry the contouring along at the same time with the original plotting.

The map should be finished as shown, and, if necessary, a report submitted with it calling attention to features that were omitted, such, for example, as artillery positions too distant to be plotted to scale. The position of the picket and of all roads in rear of the line of observation should be accurately shown.

RECONNAISSANCE OF POSITIONS.—*A defensive position* is one affording protection from the shot and observation of an enemy, and, at the same time, commanding the ground in front, within range.

In order to reconnoiter and report intelligently on a position, it will be necessary to bear in mind the following principles and conditions which a good position should fulfill:

(1.) *A position should conform to the special tactical requirements of the occasion, and should be such as to favor the use of the relatively strongest arm.*

(2.) *It should be made impossible for the enemy to obtain natural cover during his advance. In other words, the position should have a "free field of fire."*

(3.) *The defenders should be protected from the fire and view of the enemy naturally, or by cover so arranged as not to interfere with counter-attacks.*

(4.) *The advance of the enemy should be hindered by obstacles so arranged that he may be checked while under the fire of the defenders.*

(5.) *The depth and communications should be such that the defenders may freely move from one part of the position to another, while the contrary should obtain with respect to the enemy's ground in front.*

A position which has all the above advantages will seldom be found, nor will a commander, as a rule, have the opportunity of choosing his position and there awaiting attack, but will have to make the best of the ground on which the turn of

events has found him, fortunate if within a few miles he can find such as will give his troops any advantage.*

The best way of proceeding in the reconnaissance of a position is to begin at about 4,000 yards "in front" of the position, so as first to reconnoiter it from the point of view of the attack; moving thence towards the position, thus considering its capabilities from both the assailants' and defenders' points of view.

The following points would be reconnoitered:

(1.) *The ground in front.* (From the limit of effective artillery range up to the effective range of rifle.)

**Slopes admitting of maneuvers:*

From 0° to 5°	1.	Infantry can move in formations.
	2.	Cavalry can move with order; its charge more effective up hill than down.
	3.	Artillery fire more effective down than up hill.
5° to 10°	1.	Close movements difficult
	2.	Charge possible up hill only, and for a short distance.
	3.	Moves with difficulty; effectual and constant fire ceases.
10° to 15°	1.	Can move but a very short distance in order.
	2.	Can trot but a short distance up hill, and walk down.
	3.	Moves with great difficulty; its fire ceases.

Slopes which may be ascended and descended singly:

15° to 20°	1.	Cannot move in order; can only fire singly with effect.
	2.	Can ascend at a walk, and descend obliquely.
20° to 25°	1.	Can move in extended order only.
	2.	Can ascend and descend obliquely, one by one.
25° to 30°	1.	Can move in extended order only and very slowly.
	2.	As before, when the slope is of soft earth, but with great difficulty.

Slopes which may be climbed:

30° to 35°	—1.	Lightly equipped, slowly in extended order.
35° to 40°	—1.	As before, with help of their hands.
40° to 45°	—1.	Men accustomed to hilly country may climb, holding on by their hands, but with danger of falling.

The nature of the surface, as well as the steepness, affects the capabilities of ground for the movements of troops and affects the three arms differently. Infantry can ascend a steep slope easier if the surface is rocky and rugged than if it is smooth turf. For cavalry the latter is easier.

Positions favorable for artillery of assailant; undulations; obstacles; cover; points on or in front of position where the fire of the defense might tell effectively on assailants; the slopes; communications; defiles; bridges; fords; etc.

(2.) *The approaches.* (Ground within effective rifle range of position.)

Same as (1) with regard to rifle fire; parts accessible or inaccessible; also points that may be used as advance posts.

(3.) *Main line of position.* (To be marked on sketch.)

Command; extent of front; artillery positions; hedges, fences, walls, to be prepared for defense; positions of shelter trenches; cover for firing line, supports and reserves; points of support (woods, farms, etc.) in detail; nature of soil; lateral communications, work necessary to improve them.

(4.) *The flanks.*

Natural obstacles, if any, as small woods, steep slopes, rivers, etc. If none, points that may be occupied by artillery, or defensive posts in prolongation of main line, in front or rear of flanks.

(5.) *The interior.*

Depth; cover; slopes; position for second line and cavalry; communications; points of support; nature of soil.

(6.) *The ground in rear.*

Lines of retreat; obstacles; positions for rallying line, if required.

The sketch. A *good sketch* is far preferable to a written description of a position, for one who can read a map. And however pressed for time one may be, *he should try* to convey as much information by *a sketch* as circumstances will permit. The scale should be not less than about 6 inches to a mile, to show certain details more accurately than could be done on a smaller scale.

The report. This will, of course, explain all points in which the sketch is deficient. Frequently the officer will be given a government map of the country, and be required to simply *draw up a report* furnishing all the tactical information

in which the map may be deficient, or to make a copy on the required scale and then on arriving on the ground fill in the details not marked and correct those that have changed. It is not the business of the reconnoitering officer to suggest the proper method of occupying a position, unless specially ordered to do so. He will merely give the result of his observations, explain the points of weakness and strength, general capabilities, and suitability for the action of the three arms, the means which exist for obstructing an assailant's advance and retarding his pursuit, nature of communications, etc., and leave the superior officer to draw his own conclusions.

The report would be made under the following heads:

I. THE POSITION.—1, description of all that is not already explained by the sketch concerning its form; 2, the direction in which it faces; 3, its flanks; 4, any remarkable or dominating point in it; 5, the condition of the ground, whether soft and heavy for movement or the reverse; 6, probable direction of the enemy's attack, and reasons for this conclusion; 7, wood and water in case it is intended to camp or bivouac on the ground.

II. ADVANTAGES.—1, good positions for artillery, with wide and distant range commanding approaches and flanks; 2, good points of support on the front and flanks; 3, good cover for infantry, with ground in front suitable for the development of rifle fire; 4, cover for the supports and reserves; 5, communications in a lateral direction; 6, communications to the front, and the directions in which a counter-attack could be delivered; 7, communications to the rear; 8, flanks well posted; 9, extent suitable for the force; 10, natural obstacles to the enemy's advance.

III. DISADVANTAGES.—The reverse of the above. 1, limited range for artillery, or the ground affording better positions for enemy's artillery; 2, no favorable grounds on which to rest flanks; 3, no cover for firing line, or in such position that the fire would not be effective; 4, no cover in convenient

places for the supports and reserves; 5, inconvenient or poor communications; 6, extent unsuitable to strength, or its nature to the composition of defending force; 7, cover for the enemy during his advance.

IV. THE COUNTRY IN THE VICINITY.—1, general description of the surrounding country beyond the limits of the sketch; 2, positions or strong points on the line of retreat, at which pursuit might be checked, as farms, towns, etc.; 3, distant view to be obtained.

V. COMMUNICATIONS.—Description of roads, trails, etc., both parallel and perpendicular to the position; also those from the front towards the flanks.

VI. BRIDGES.—In detail as in road reports.

VII. RIVERS.—As in road reports, particularly as to points of passage and nature of banks.

VIII. WOODS.—1, its extent and form; 2, communications and paths through it; 3, average circumference of trees; 4, nature of undergrowth and its penetrability; 5, means to be adopted for the defense of the edges nearest the enemy; 6, whether timber is suitable for abattis to be placed at the salients and most exposed portions; 7, whether parts of the edge flank other parts; 8, whether the wood is quite isolated, or is connected with neighboring woods by scattering timber; 9, whether there are any folds in the ground, or any bank that would give shelter to an enemy close in front of it; 10, same in rear of the wood whence fire might be brought to bear on its near edge to prevent the enemy from issuing from it, in case he should succeed in capturing it.

IX. FARMS AND VILLAGES.—1, whether compact or straggling; 2, exterior surrounded by walls or fences suitable for defense; 3, whether fences beyond would cover enemy in his advance; 4, means of retarding advance; 5, whether commanded by artillery positions on enemy's or defender's side; 6, full details concerning buildings suitable for a réduit, as churches, etc.

X. FENCES.—Full details of those shown on sketch which it is proposed to utilize for defense.

XI. OBSTRUCTIONS, DEMOLITIONS, TRENCHES, AND OTHER WORKS.—Details of these to be submitted on a separate report if required, showing kinds, time required, number of reliefs, number of men in each relief, tools required, etc.

(Note example of position sketch and report.)

CHAPTER XXV.

LAYING OUT ROADS.

SELECTION OF SITE.—*Use of maps.* If a contoured map of the country is available, that which is probably the best line may be selected from it. An idea of a possible site may be obtained from any existing map. On account of drainage, water-sheds are more advantageous than either water-courses or hill-sides.

Ruling points. The road should be so located as to require the least amount of labor and expense, due regard being paid to direction and gradients. There will usually be some feature whose passage will be difficult. The part of this feature that can be passed most easily will constitute a *ruling point*, provided it is not too far out of the direct line of the road. A col in a chain of mountains would be such a point.

Secondary points. Between ruling points other points of less importance are chosen. These are called *secondary points* and in their selection there is much latitude. Ruling and secondary points are usually determined by an inspection of the ground. After this inspection, the possible lines would be compared and the best one selected.

LAYING OUT THE GRADE.—This may be done with a pair of dividers on a contoured map, or with the clinometer, slope board, or transit on the ground.

On a contoured map the maximum gradient is specified in the instructions. Take off on the dividers, from the scale of horizontal equivalents, the distance corresponding to the maximum slope. Should the distance between contours be greater than this, the road can have any desired direction. Should

the distance be less, the road must be run obliquely between contours so as to make the distance between them equal to or greater than that corresponding to the maximum slope.

On the ground. Standing at one point of the road, direct an assistant to move up or down the hill until he comes to a point on the *desired slope*, as indicated by the instrument used. A picket is driven into the ground at this point and, if required, its bearing from the preceding point taken. The maximum gradient should be used only where absolutely necessary, a smaller one being chosen when practicable, so as to make the gradient as uniform as possible throughout. The work of marking the center grade line is continued until a ruling point is reached. Should the line surveyed run above or below the ruling point, the pickets will have to be shifted in order to equalize the gradient throughout, or, if this be not possible, a new line between ruling points will have to be run.

Leveling to grade between pickets. This is done with the clinometer, slope board, or transit. The instrument is taken to one picket and set to read the slope to the next picket. An assistant then moves along the line between pickets and at the points of change of slope drives in stakes and marks on them the amount of cut or fill as indicated by a rod or staff carried for this purpose. *a* and *b* (Fig. 215) are the positions of the pickets at points of grade. The position of the target on the

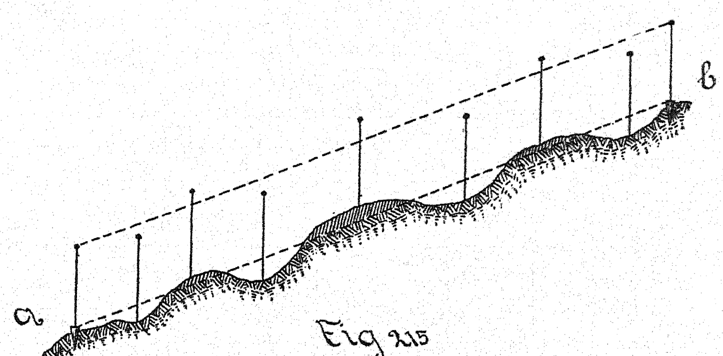


Fig 215

rod held at the intermediate points shows the amount of cut or fill.

LAYING OUT THE SECTION.—In rough work this may be done with any instrument that can be used as a level; for accuracy the wye level is necessary. This operation is sometimes called *cross-section leveling*.

The required width of the road is measured off horizontally from the center line and the exact edges marked by means of stakes or by scoring the ground.

The required slope of the road bed from center to sides is usually specified in the instructions. If not specified, it must be assumed and the difference of level between the center and side stakes computed. The amount of cut or fill at any point

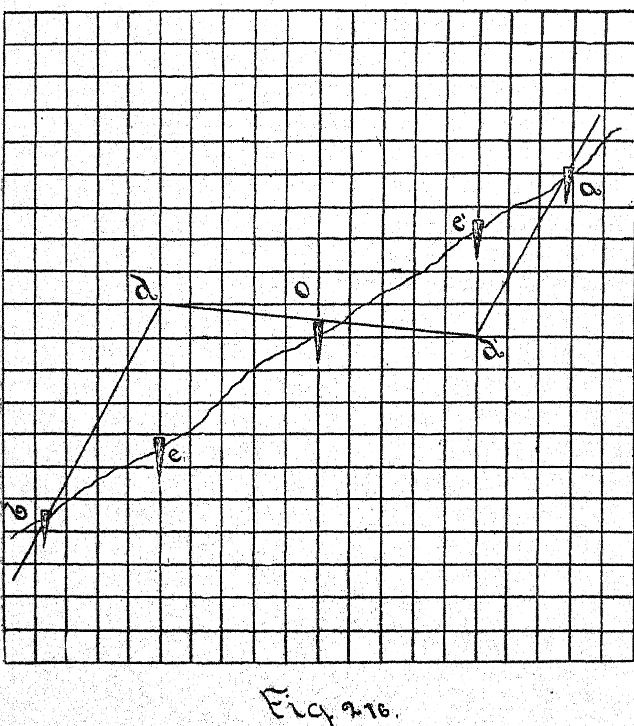


Fig. 216.

along the central grade line being known, the amount at the sides corresponding to it can be computed and marked on the side stakes.

Side slopes. To locate the slope stakes. Having the readings on the center and side stakes, a rough profile of the ground should be constructed on cross-section paper carried for the purpose. The location of the stakes for the side slopes is then determined as follows: Suppose *ab* (Fig. 216) to be the profile showing the natural surface of the ground as determined by the level, *o* being the position of a central picket. Plot *d* and *d'* on the diagram, their position having been computed as explained. Draw *dd'*; then from *d* and *d'* draw *db* and *d'a*, having an inclination corresponding to the required side slopes. The points where these last lines intersect the line *ab* will be the plotted positions of the bottom and top of the required slopes respectively.

The horizontal distances corresponding to *eb* and *e'a* on the diagram will be the required distances to lay off from the stakes at *e* and *e'* to determine the bottom and top of the side slopes. Stakes are driven at the points *a* and *b*.

Sections should be made about every thirty yards, or as required by the conformation of the ground.

APPENDIX.

TABLE I.—Mean Refractions.

APPARENT ALTITUDE.	REFRACTION *minus*.	APPARENT ALTITUDE.	REFRACTION *minus*.
25°	0° 2′ 4.2″	38°	0° 1′14.4″
26	1 58.8	39	1 11.8
27	1 53.8	40	1 9.3
28	1 49.1	41	1 6.9
29	1 44.7	42	1 4.6
30	1 40.5	43	1 2.4
31	1 36.6	44	1 0.3
32	1 33 0	45	0 58.1
33	1 29.5	46	0 56.1
34	1 26.1	47	0 54.2
35	1 23.0	48	0 52.3
36	1 20.0	49	0 50.5
37	1 17.1	50	0 48.8

TABLE II.—Corrections for Curvature and Refraction.

D	h_2	D	h_2	D	h_2	D	h_2
Miles.	*Feet.*	*Miles.*	*Feet.*	*Miles.*	*Feet.*	*Miles.*	*Feet.*
1.0	0.6	5.5	17.3				
1.1	0.7	5.6	18.0	3.6	7.4	8 1	37.6
1.2	0.8	5.7	18.6	3.7	7.8	8.2	38.6
1.3	1.0	5.8	19.3	3.8	8.3	8.3	39.5
1.4	1.1	5.9	20.0	3.9	8.7	8 4	40.5
1.5	1.3	6.0	20.6	4.0	9.2	8.5	41.4
1.6	1.5	6.1	21.3	4.1	9.6	8.6	42.4
1.7	1.7	6.2	22.0	4.2	10.1	8.7	43.4
1.8	1.9	6.3	22.8	4.3	10.6	8.8	44.4
1.9	2.1	6.4	23.5	4 4	11.1	8.9	45.4
2.0	2.3	6.5	24.2	4.5	11.6	9.0	46.4
2.1	2.5	6.6	25.0	4.6	12.1	9.1	47.5
2.2	2.8	6.7	25.7	4.7	12.7	9.2	48.5
2.3	3.0	6.8	26.5	4.8	13.2	9.3	49.6
2.4	3.3	6.9	27.3	4.9	13.8	9.4	50.7
2.5	3.6	7.0	28.1	5.0	14.3	9.5	51.7
2.6	3.9	7.1	28.9	5.1	14.9	9.6	52.8
2.7	4.2	7.2	29.7	5.2	15.5	9.7	53.9
2.8	4.5	7.3	30 5	5.3	16.1	9.8	55.1
2.9	4.8	7.4	31.4	5.4	16.7	9.9	56.2
3.0	5.2	7.5	32.2	5.5	17.3	10.0	57.3
3.1	5.5	7.6	33.1				
3.2	5.9	7.7	34.0				
3.3	6.2	7.8	34.9				
3.4	6.6	7.9	35.8				
3.5	7.0	8.0	36 7				

TABLE III.—Local Mean Times (astronomical, counting from noon, and from 0 to 24 hours) of the Elongations and Culminations of Polaris in the year 1893, latitude + 40° north, longitude six hours west from Greenwich.

DATE.	EAST ELONG.		UPPER CULM.		WEST ELONG.		LOWER CULM.	
1893.	Hour	Min.	Hour	Min.	Hour	Min.	Hour	Min.
Jan. 1	0	37.2	6	32.0	12	26.8	18	30.0
Feb. 1	22	30.8	4	29.6	10	24.4	16	27.6
Mar. 1	20	40 4	2	39.1	8	33.9	14	37.1
Apr. 1	18	38.3	0	37.0	6	31.8	12	35.1
May 1	16	40.5	22	35.2	4	34.0	10	37.2
June 1	14	38.9	20	33.7	2	32.4	8	35.7
July 1	12	41.4	18	36.2	0	34.9	6	38.2
Aug. 1	10	40.0	16	34.8	22	29.6	4	36.8
Sept. 1	8	38.5	14	33.3	20	28.1	2	35.3
Oct. 1	6	40.8	12	35.6	18	30.4	0	37.6
Nov. 1	4	39.0	10	33.8	16	28.6	22	31.8
Dec. 1	2	40.8	8	35.6	14	30.4	20	33.6

For other days of each month subtract 3.94 minutes for each day from that of 1st. Thus for 2d subtract 3.94 min.; for 3d subtract 7.98 min.; for 4th subtract 11.82 min., etc.

For other years than 1893 add to the above 0.25 min. for every additional year; also add

0.0 min. if the year is the first after leap-year.
0.9 min. if the year is the second after leap-year.
1.7 min. if the year is the third after leap-year.
2.6 min. if the year is leap-year before March 1st.
Subtract 1.2 min. if the year is leap-year after March 1st.

For longitude correction add 0.16 min. for each hour east of the 6 hour, and subtract 0.16 min. for each hour west of the 6 hour meridian.

For other latitudes between 25° and 50° north, *add* to time of west elongation 0.13 min. for every degree south of latitude 40°; and *subtract* 0.18 min. for every degree north of latitude 40°; reverse these signs for corrections to the times of east elongations.

The year 1900 will not be a leap-year for dealing with the dates before and after March 1st of that year. The 20th century begins after December 31, 1900.

TABLE IV.—Azimuths of Polaris (from the north pole) at elongation, between 1895 and 1910, for different latitudes between 25° and 49° north.

Latitude.	1895	1896	1897	1898	1899	1900	1901	1902
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
25	1 22 9	1 22.5	1 22.2	1 21.8	1 21.5	1 21.2	1 20.8	1 20.5
26	23.6	23.2	22.9	22.5	22.2	21 8	21.5	21.1
27	24.3	24.0	23.6	23.3	22.9	22.5	22.2	21.9
28	25.1	24.7	24.4	24.0	23.7	23.3	23.0	22.6
29	25.9	25.5	25.2	24.8	24.5	24.1	23.8	23.4
30	1 26.8	1 26.4	1 26.0	1 25.7	1 25.3	1 24.9	1 24.6	1 24.2
31	27.6	27.3	26.9	26.5	26.2	25.8	25.5	25.1
32	28.6	28.2	27.9	27.5	27.1	26.7	26.4	26.0
33	29.6	29.2	28.8	28.5	28.1	27.7	27.3	27.0
34	30.6	30.2	29.9	29.5	29.1	28.7	28.4	28.0
35	1 31.7	1 31.3	1 30.9	1 30.6	1 30.2	1 29.8	1 29.4	1 29.0
36	32.9	32.5	32.1	31.7	31 3	30.9	30.5	30.1
37	34.1	33.7	33.3	32.9	32.5	32.1	31.7	31.3
38	35.3	35.0	34.6	34.2	33.8	33.4	33.0	32.6
39	36.7	36.3	35.9	35.5	35.1	34.7	34.3	33 9
40	1 38.1	1 37.7	1 37.2	1 36.8	1 36.4	1 36.0	1 35.6	1 35.2
41	39.6	39.1	38.7	38.3	37.9	37.5	37.1	36.7
42	41.1	40.7	40.3	39.8	39.4	39.0	38 6	38.2
43	42 7	42.3	41 9	41.4	41.0	40.6	40.2	39.8
44	44.4	44.0	43.6	43.1	42.7	42.3	41.8	41.4
45	1 46.2	1 45.8	1 45.4	1 44.9	1 44.5	1 44.0	1 43.6	1 43.2
46	48.2	47.7	47.2	46.8	46.3	45.9	45.5	45.0
47	50.2	49.7	49.2	48.8	48.3	47.9	47.4	46.9
48	52.3	51.8	51.3	50.9	50.4	49.9	49.5	49.0
49	54 5	54.1	53.6	53.1	52.6	52 1	51.7	51.2

Latitude.	1903	1904	1905	1906	1907	1908	1909	1910
°	° ′	° ′	°	° ′	° ′	° ′	° ′	° ′
25	1 20.1	1 19.8	1 19.4	1 19.1	1 18 7	1 18.4	1 18.1	1 17.7
26	20.8	20.5	20.1	19.8	19.4	19.1	18.7	18.4
27	21.5	21.2	20.8	20.5	20.1	19.8	19.4	19.1
28	22.2	21.9	21.6	21.3	20.9	20.5	20.1	19.8
29	23.0	22.7	22.4	22.1	21.7	21.3	20.9	20.5
30	1 23 9	1 23.5	1 23.1	1 22.8	1 22.4	1 22.1	1 21.7	1 21.3
31	24.7	24.4	24.0	23.6	23.2	22.9	22.5	22.2
32	25 6	25.3	24.9	24.5	24.1	23.8	23.4	23.1
33	26.6	26.2	25.9	25.5	25.1	24.7	24.3	24.0
34	27.6	27.2	26.9	26.5	26.1	25.7	25.3	25.0
35	1 28.7	1 28.3	1 27.9	1 27.5	1 27.1	1 26.8	1 26.4	1 26.0
36	29.8	29.4	29.0	28.6	28.2	27.9	27.5	27.1
37	30.9	30.5	30.1	29.7	29.3	29.0	28.6	28.2
38	32.2	31.8	31.4	31.0	30.6	30.2	29.8	29.4
39	33.5	33.1	32.7	32.3	31.8	31.4	31.0	30.6
40	1 34.8	1 34.4	1 34.0	1 33.6	1 33.2	1 32.8	1 32.4	1 32.0
41	36.2	35.8	35.4	35.0	34.6	34 2	33.8	33.4
42	37.7	37.3	36.9	36.5	36.0	35.6	35.2	34 8
43	39.3	38.9	38.5	38.1	37.6	37.2	36.8	36.3
44	41.0	40.5	40.1	39.7	39.2	38 8	38.4	37.9
45	1 42.7	1 42 3	1 41.8	1 41.4	1 40.9	1 40.5	1 40.1	1 39.6
46	44.6	44.2	43.7	43.2	42.7	42.3	41.9	41.4
47	46 5	46.0	45.6	45.1	44.6	44.2	43.7	43 3
48	48.6	48.1	47.7	47.2	46.7	46.3	45.8	45.3
49	50.7	50.2	49.8	49.3	48.8	48.4	47.9	47.4

TABLE III.—Local Mean Times (astronomical, counting from noon, and from 0 to 24 hours) of the Elongations and Culminations of Polaris in the year 1893, latitude + 40° north, longitude six hours west from Greenwich.

DATE.	EAST ELONG.		UPPER CULM.		WEST ELONG.		LOWER CULM.	
1893.	Hour	Min.	Hour	Min.	Hour	Min.	Hour	Min.
Jan. 1	0	37.2	6	32.0	12	26.8	18	30.0
Feb. 1	22	30.8	4	29.6	10	24.4	16	27.6
Mar. 1	20	40 4	2	39.1	8	33.9	14	37.1
Apr. 1	18	38.3	0	37.0	6	31.8	12	35.1
May 1	16	40.5	22	35.2	4	34.0	10	37.2
June 1	14	38.9	20	33.7	2	32.4	8	35.7
July 1	12	41.4	18	36.2	0	34.9	6	38.2
Aug. 1	10	40.0	16	34.8	22	29.6	4	36.8
Sept. 1	8	38.5	14	33.3	20	28.1	2	35.3
Oct. 1	6	40.8	12	35.6	18	30.4	0	37.6
Nov. 1	4	39.0	10	33.8	16	28.6	22	31.8
Dec. 1	2	40.8	8	35.6	14	30.4	20	33.6

For other days of each month subtract 3.94 minutes for each day from that of 1st. Thus for 2d subtract 3.94 min.; for 3d subtract 7.98 min.; for 4th subtract 11.82 min., etc.

For other years than 1893 add to the above 0.25 min. for every additional year; also add

0.0 min. if the year is the first after leap-year.
0.9 min. if the year is the second after leap-year.
1.7 min. if the year is the third after leap-year.
2.6 min. if the year is leap-year before March 1st.
Subtract 1.2 min. if the year is leap-year after March 1st.

For longitude correction add 0.16 min. for each hour east of the 6 hour, and subtract 0.16 min. for each hour west of the 6 hour meridian.

For other latitudes between 25° and 50° north, *add* to time of west elongation 0.13 min. for every degree south of latitude 40°; and *subtract* 0.18 min. for every degree north of latitude 40°; reverse these signs for corrections to the times of east elongations.

The year 1900 will not be a leap-year for dealing with the dates before and after March 1st of that year. The 20th century begins after December 31, 1900.

TABLE IV.—Azimuths of Polaris (from the north pole) at elongation, between 1895 and 1910, for different latitudes between 25° and 49° north.

Latitude.	1895	1896	1897	1898	1899	1900	1901	1902
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
25	1 22.9	1 22.5	1 22.2	1 21.8	1 21.5	1 21.2	1 20.8	1 20.5
26	23.6	23.2	22.9	22.5	22.2	21.8	21.5	21.1
27	24.3	24.0	23.6	23.3	22.9	22.5	22.2	21.9
28	25.1	24.7	24.4	24.0	23.7	23.3	23.0	22.6
29	25.9	25.5	25.2	24.8	24.5	24.1	23.8	23.4
30	1 26.8	1 26.4	1 26.0	1 25.7	1 25.3	1 24.9	1 24.6	1 24.2
31	27.6	27.3	26.9	26.5	26.2	25.8	25.5	25.1
32	28.6	28.2	27.9	27.5	27.1	26.7	26.4	26.0
33	29.6	29.2	28.8	28.5	28.1	27.7	27.3	27.0
34	30.6	30.2	29.9	29.5	29.1	28.7	28.4	28.0
35	1 31.7	1 31.3	1 30.9	1 30.6	1 30.2	1 29.8	1 29.4	1 29.0
36	32.9	32.5	32.1	31.7	31.3	30.9	30.5	30.1
37	34.1	33.7	33.3	32.9	32.5	32.1	31.7	31.3
38	35.3	35.0	34.6	34.2	33.8	33.4	33.0	32.6
39	36.7	36.3	35.9	35.5	35.1	34.7	34.3	33.9
40	1 38.1	1 37.7	1 37.2	1 36.8	1 36.4	1 36.0	1 35.6	1 35.2
41	39.6	39.1	38.7	38.3	37.9	37.5	37.1	36.7
42	41.1	40.7	40.3	39.8	39.4	39.0	38.6	38.2
43	42.7	42.3	41.9	41.4	41.0	40.6	40.2	39.8
44	44.4	44.0	43.6	43.1	42.7	42.3	41.8	41.4
45	1 46.2	1 45.8	1 45.4	1 44.9	1 44.5	1 44.0	1 43.6	1 43.2
46	48.2	47.7	47.2	46.8	46.3	45.9	45.5	45.0
47	50.2	49.7	49.2	48.8	48.3	47.9	47.4	46.9
48	52.3	51.8	51.3	50.9	50.4	49.9	49.5	49.0
49	54.5	54.1	53.6	53.1	52.6	52.1	51.7	51.2

Latitude.	1903	1904	1905	1906	1907	1908	1909	1910
°	° ′	° ′	°	° ′	° ′	° ′	° ′	° ′
25	1 20.1	1 19.8	1 19.4	1 19.1	1 18.7	1 18.4	1 18.1	1 17.7
26	20.8	20.5	20.1	19.8	19.4	19.1	18.7	18.4
27	21.5	21.2	20.8	20.5	20.1	19.8	19.4	19.1
28	22.2	21.9	21.6	21.3	20.9	20.5	20.1	19.8
29	23.0	22.7	22.4	22.1	21.7	21.3	20.9	20.5
30	1 23.9	1 23.5	1 23.1	1 22.8	1 22.4	1 22.1	1 21.7	1 21.3
31	24.7	24.4	24.0	23.6	23.2	22.9	22.5	22.2
32	25.6	25.3	24.9	24.5	24.1	23.8	23.4	23.1
33	26.6	26.2	25.9	25.5	25.1	24.7	24.3	24.0
34	27.6	27.2	26.9	26.5	26.1	25.7	25.3	25.0
35	1 28.7	1 28.3	1 27.9	1 27.5	1 27.1	1 26.8	1 26.4	1 26.0
36	29.8	29.4	29.0	28.6	28.2	27.9	27.5	27.1
37	30.9	30.5	30.1	29.7	29.3	29.0	28.6	28.2
38	32.2	31.8	31.4	31.0	30.6	30.2	29.8	29.4
39	33.5	33.1	32.7	32.3	31.8	31.4	31.0	30.6
40	1 34.8	1 34.4	1 34.0	1 33.6	1 33.2	1 32.8	1 32.4	1 32.0
41	36.2	35.8	35.4	35.0	34.6	34.2	33.8	33.4
42	37.7	37.3	36.9	36.5	36.0	35.6	35.2	34.8
43	39.3	38.9	38.5	38.1	37.6	37.2	36.8	36.3
44	41.0	40.5	40.1	39.7	39.2	38.8	38.4	37.9
45	1 42.7	1 42.3	1 41.8	1 41.4	1 40.9	1 40.5	1 40.1	1 39.6
46	44.6	44.2	43.7	43.2	42.7	42.3	41.9	41.4
47	46.5	46.0	45.6	45.1	44.6	44.2	43.7	43.3
48	48.6	48.1	47.7	47.2	46.7	46.3	45.8	45.3
49	50.7	50.2	49.8	49.3	48.8	48.4	47.9	47.4

TABLE V. Horizontal Distances and Elevations for inclined stadia readings.

	0°		1°		2°		3°	
Minutes.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23
2	"	0.06	"	.80	.87	.55	.72	.28
4	"	0.12	"	.86	"	.60	.71	.34
6	"	0.17	.96	.92	"	.66	"	.40
8	"	0 23	"	98	.86	.72	.70	.46
10	"	0.29	"	2 04	"	.78	.69	.52
12	"	0.35	"	.09	.85	.84	"	.57
14	"	0.41	.95	.15	"	.90	.68	.63
16	"	0.47	"	.21	.84	.95	"	.69
18	"	0.52	"	.27	"	4.01	.67	.75
20	"	0.58	"	.33	.83	.07	.66	.80
22	"	0.64	94	.38	"	.13	"	.86
24	"	0.70	"	.44	.82	.18	.65	.92
26	99.99	0.76	"	.50	"	.24	.64	.98
28	"	0.81	.93	.56	.81	.30	.63	6.04
30	"	0 87	"	.62	"	.36	"	.09
32	"	0 93	"	.67	.80	.42	.62	.15
34	"	0.99	"	.73	"	.48	"	21
36	"	1.05	.92	.79	.79	.53	.61	.27
38	"	1 11	"	.85	"	59	.60	.33
40	"	1.16	"	.91	.78	.65	.59	.38
42	"	1.22	.91	.97	"	.71	"	.44
44	99.98	1.28	"	3.02	.77	.76	.58	.50
46	"	1 34	.90	.08	"	.82	.57	.56
48	"	1.40	"	.14	.76	.88	.56	.61
50	"	1.45	"	.20	"	.94	"	.67
52	"	1.51	.89	.26	.75	.99	.55	.73
54	"	1.57	"	.31	.74	5.05	.54	.78
56	99.97	1.63	"	.37	"	.11	.53	.84
58	"	1.69	.88	.43	.73	.17	.52	.90
60	"	1.74	"	.49	"	.23	.51	.96
c=0.75	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05
c=1.00	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06
c=1 25	1.25	0.02	1.25	0.03	1 25	0.05	1.25	0.08

TABLE V.—*Continued.* Horizontal Distances and Elevations for inclined stadia readings.

Minutes.	4° Hor. Dist.	4° Diff. Elev.	5° Hor. Dist.	5° Diff. Elev.	6° Hor. Dist.	6° Diff. Elev.	7° Hor. Dist.	7° Diff. Elev.
0	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10
2	"	7.02	.23	.74	.90	.45	.50	.15
4	.50	.07	.22	.80	.88	.51	.48	.21
6	.49	.13	.21	.85	.87	.57	.47	.26
8	.48	.19	.20	.91	.86	.62	.46	.32
10	.47	.25	.19	.97	.85	.68	.44	.38
12	.46	.30	.18	9.03	.83	.74	.43	.43
14	"	.36	.17	.08	.82	.79	.41	.49
16	.45	.42	.16	.14	.81	.85	.40	.55
18	.44	.48	.15	.20	.80	.91	.39	.60
20	.43	.53	.14	.25	.78	.96	.37	.66
22	.42	.59	.13	.31	.77	11.02	.36	.72
24	.41	.65	.11	.37	.76	.08	.34	.77
26	.40	.71	.10	.43	.74	.13	.33	.83
28	.39	.76	.09	.48	.73	.19	.31	88
30	.38	.82	.08	.54	.72	.25	.29	.94
32	"	.88	.07	.60	.71	.30	.28	13.00
34	.37	.94	06	.65	.69	.36	.27	.05
36	.39	.99	.05	.71	.68	.42	.25	.11
38	.35	8.05	.04	.77	.67	.47	.24	.17
40	.34	.11	.03	.83	.65	.53	22	.22
42	.33	.17	.01	.88	.64	.59	.20	.28
44	.32	.22	.00	.94	.63	.64	.19	.33
46	.31	.28	98.99	10.00	.61	.70	.17	.39
48	.30	.34	98	.05	.60	.76	.16	.45
50	.29	.40	.97	.11	.58	.81	.14	.50
52	.28	.45	.96	.17	.57	.87	.13	.56
54	.27	.51	.94	.22	.56	.93	.11	.61
56	.26	.57	.93	.28	.54	.98	.10	67
58	.25	.63	.92	.34	.53	12.04	.08	.73
60	.24	.68	.91	.40	.51	.10	.06	.78
c=0 75	0.75	0.06	0.75	0.07	0.75	0.08	0.74	0 10
c=1.00	1.00	0.08	0.99	0.09	0.99	0.11	0.99	0.13
c=1.25	1.25	0.10	1.24	0.11	1.24	0.14	1.24	0.16

TABLE V.—*Continued.* Horizontal Distances and Elevations for inclined stadia readings.

Minutes.	8° Hor. Dist.	8° Diff. Elev.	9° Hor. Dist.	9° Diff. Elev.	10° Hor. Dist.	10° Diff. Elev.	11° Hor. Dist.	11° Diff. Elev.
0	98.06	13 78	97.55	15.45	96.98	17.10	96.36	18.73
2	.05	.84	.53	.51	.96	.16	.34	.78
4	.03	.89	.52	.56	.94	.21	.32	.84
6	.01	.95	.50	.62	.92	.26	.29	.89
8	.00	14.01	.48	.67	.90	.32	.27	.95
10	97.98	.06	.46	.73	.88	.37	.25	19.00
12	.97	.12	.44	.78	.86	.43	.23	.05
14	.95	.17	.43	.84	.84	.48	.21	.11
16	.93	.23	.41	.89	.82	.54	.18	.16
18	.92	.28	.39	.95	.80	.59	.16	.21
20	.90	.34	.37	16.00	.78	.65	.14	.27
22	.88	.40	.35	.06	.76	.70	.12	.32
24	.87	.45	.33	.11	.74	.76	.09	.38
26	.85	.51	.31	.17	.72	.81	.07	.43
28	.83	.56	.29	.22	.70	.86	.05	.48
30	.82	.62	.28	.28	.68	.92	.03	.54
32	.80	.67	.26	.33	.66	.97	96.00	.59
34	.78	.73	.24	.39	.64	18.03	95.98	.64
36	.76	.79	.22	.44	.62	.08	.96	.70
38	.75	.84	.20	.50	.60	.14	.93	.75
40	.73	.90	.18	.55	.57	.19	.91	.80
42	.71	.95	.16	.61	.55	.24	.89	.86
44	.69	15.01	.14	.66	.53	.30	.86	.91
46	.68	.06	.12	.72	.51	.35	.84	.96
48	.66	.12	.10	.77	.49	.41	.82	20.02
50	.64	.17	.08	.83	.47	.46	.79	.07
52	.62	.23	.06	.88	.45	.51	.77	.12
54	.61	.28	.04	.94	.42	.57	.75	.18
56	.59	.34	.02	.99	.40	.62	.72	.23
58	.57	.40	.00	17.05	.38	.68	.70	.28
60	.55	.45	96.98	17.10	.36	.73	.68	.34
c=0.75	0.74	0.11	0.74	0.12	0.74	0.14	0.73	0.15
c=1.00	0.99	0.15	0.99	0.16	0.98	0.18	0.98	0.20
c=1.25	1.23	0.18	1.23	0.21	1.23	0.23	1.22	0.25

TABLE V.—*Continued.* Horizontal Distances and Elevations for inclined stadia readings.

Minutes.	12° Hor. Dist.	12° Diff. Elev.	13° Hor. Dist.	13° Diff. Elev.	14° Hor. Dist.	14° Diff. Elev.	15° Hor. Dist.	15° Diff. Elev.
0	95.68	20 34	94.94	21.92	94.15	23.47	93.30	25.00
2	.65	.39	.91	.97	.12	.52	.27	.05
4	.63	.44	.89	22.02	.09	.58	.24	.10
6	.61	.50	.86	.08	.07	.63	.21	.15
8	.58	.55	.84	.13	.04	.68	.18	.20
10	.56	.60	.81	.18	.01	.73	.16	.25
12	.53	.66	.79	.23	93.98	.78	.13	.30
14	.51	.71	.76	.28	.95	.83	.10	.35
16	.49	.76	.73	.34	.93	.88	.07	.40
18	.46	.81	.71	.39	.90	.93	.04	.45
20	.44	.87	.68	.44	.87	.99	.01	.50
22	.41	.92	.66	.49	.84	24.04	92.98	.55
24	.39	.97	.63	.54	.81	.09	.95	.60
26	.36	21.03	.60	.60	.79	.14	.92	.65
28	.34	.08	.58	.65	.76	.19	.89	.70
30	.32	.13	.55	.70	.73	.24	.86	.75
32	.29	.18	.52	.75	.70	.29	.83	.80
34	.27	.24	.50	.80	.67	.34	.80	.85
36	.24	.29	.47	.85	.65	.39	.77	.90
38	.22	.34	.44	.91	.62	.44	.74	.95
40	.19	.39	.42	.96	.59	.49	.71	26.00
42	.17	.45	.39	23.01	.56	.55	.68	.05
44	.14	.50	.36	.06	.53	.60	.65	.10
46	.12	.55	.34	.11	.50	.65	.62	.15
48	.09	.60	.31	.16	.47	.70	.59	.20
50	.07	.66	.28	.22	.45	.75	.56	.25
52	.04	.71	.26	.27	.42	.80	.53	.30
54	.02	.76	.23	.32	.39	.85	.49	.35
56	94.99	.81	.20	.37	.36	.90	.46	.40
58	.97	.87	.17	.42	.33	.95	.43	.45
60	.94	.92	.15	.47	.30	25.00	.40	.50
c=0.75	0.73	0.16	0.73	0.17	0.73	0.19	0.72	0.20
c=1.00	0.98	0.22	0.97	0.23	0.97	0.25	0.96	0.27
c=1.25	1.22	0.27	1.21	0.29	1.21	0.31	1.20	0.34

TABLE VI.—A Table of Mean Refractions in Declination.

To apply on the declination arc of Solar Attachment of either Compasses or Transits.

DECLINATIONS.

HOUR ANGLE.	+20°	+15°	+10°	+5°	0°	—5°	—10°	—15°	—20°
				FOR LATITUDE 25°.					
0 Hour.	05″	10″	15″	21″	27″	33″	40″	48″	57″
2	08	14	19	25	31	38	46	54	1′05
3	12	18	24	30	37	44	53	1′04	1 18
4	23	29	35	45	53	1′03	1′16	1 31	1 52
5	49	59	1′10	1′24	1′52	2 07	2 44	3 46	5 43
				FOR LATITUDE 27° 30′.					
0 Hour.	08″	13″	18″	24″	30″	36″	44″	52″	1′02″
2	11	16	22	28	34	41	49	1′00	1 10
3	17	22	28	35	42	50	1′00	1 11	1 26
4	28	35	42	50	1′00	1′11	1 26	1 43	2 09
5	54	1′05	1′18	1′34	1 54	2 24	3 11	4 38	8 15
				FOR LATITUDE 30°.					
0 Hour.	10″	15″	21″	27″	33″	40″	48″	57″	1′08″
2	14	19	25	31	38	46	54	1′05	1 18
3	20	26	32	39	47	55	1′06	1 19	1 36
4	32	39	46	52	1′06	1′19	1 35	1 57	2 29
5	1′00	1′10	1′24	1′52	2 07	2 44	3 46	5 43	13 06
				FOR LATITUDE 32° 30′.					
0 Hour.	13″	18″	24″	30″	36″	44″	52″	1′02″	1′14″
2	17	22	28	35	42	50	1′00	1 11	1 26
3	23	29	35	43	51	1′01	1 13	1 28	1 47
4	35	43	51	1′01	1′13	1 27	1 46	2 13	2 54
5	1′03	1′15	1′31	1 53	2 20	3 05	4 25	7 36	
				FOR LATITUDE 35°.					
0 Hour.	15″	21″	27″	33″	40″	48″	57″	1′08″	1′21″
2	20	25	32	38	46	55	1′05	1 18	1 35
3	26	33	39	47	56	1′07	1 21	1 38	2 00
4	39	47	56	1′07	1′20	1 36	1 59	2 32	3 25
5	1′07	1′20	1′38	2 00	2 34	3 29	5 14	10 16	
				FOR LATITUDE 37° 30′.					
0 Hour.	18″	24″	30″	36′	44″	52″	1′02″	1′14″	1′29″
2	22	28	35	42	50	1′00	1 12	1 26	1 45
3	29	36	43	52	1′02	1 14	1 29	1 49	2 16
4	43	51	1′01	1′13	1 27	1 49	2 14	2 54	4 05
5	1′11	1′26	1 44	2 10	2 49	3 55	6 15	14 58	

TABLE VI.—*Continued.*. A Table of Mean Refractions in Declination.

DECLINATIONS.

HOUR ANGLE.	+20°	+15°	+10°	+ 5°	0°	—5°	—10°	—15°	—20°
FOR LATITUDE 40°.									
0 Hour.	21″	27″	33″	40″	48″	57″	1′08	1′21″	1′35″
2	25	32	39	46	52	1′06	1 19	1 35	1 57
3	33	40	48	57	1′08	1 21	1 38	2 02	2 36
4	47	55	1′06	1′19	1 36	1 58	2 30	3 21	4 59
5	1′15	1′31	1 51	2 20	3 05	4 25	7 34	25 18	
FOR LATITUDE 42° 30′.									
0 Hour.	24″	30″	36″	44″	52″	1′02″	1′14″	1′29″	1′49″
2	28	35	39	50	1′00	1 12	1 26	1 45	2 11
3	36	43	52	1′02	1 13	1 29	1 49	2 17	2 59
4	50	1′00	1′11	1 26	1 44	2 10	2 49	3 55	6 16
5	1′16	1 36	1 58	2 30	3 22	5 00	9 24		
FOR LATITUDE 45°.									
0 Hour.	27″	33″	40″	48″	57″	1′08″	1′21″	1′39″	2′02″
2	32	39	46	52	1′06	1 19	1 35	1 57	2 29
3	40	47	56	1′07	1 21	1 38	2 00	2 34	3 29
4	54	1′04	1′16	1 33	1 54	2 24	3 11	4 38	8 15
5	1′23	1 41	2 05	2 41	3 40	5 40	12 02		
FOR LATITUDE 47° 30′.									
0 Hour.	30″	36″	44″	52″	1′02″	1′14″	1′29″	1′49″	2′18″
2	35	42	50	1′00	1 12	1 26	1 45	2 01	2 51
3	43	51	1′01	1 13	1 28	1 47	2 15	2 56	4 08
4	56	1′09	1 23	1 40	2 05	2 40	3 39	5 37	11 18
5	1′27	1′46	2 12	2 52	4 01	6 30	16 19		
FOR LATITUDE 50°.									
0 Hour.	33″	40″	48″	57″	1′08″	1′21″	1′39″	2′02″	2′36″
2	38	46	55	1′06	1 18	1 35	1 57	2 28	3 19
3	47	56	1′06	1 19	1 36	2 29	2 31	3 23	5 02
4	1′02	1′14	1 29	1 48	2 16	2 58	4 18	6 59	19 47
5	1 30	1 51	2 19	3 04	4 22	7 28	24 10		

Explanation of the Table of Refractions.—The table is calculated for latitudes between 25° and 50° at intervals of 2½°, that being as near as is required.

The declination ranges from 0 to 20° both north and south, the + declinations being north, and — south, and is given for every five degrees, that being sufficiently near for all practical purposes.

The hour angle in the first column indicates the distance of the sun from the meridian in hours, the refraction given for 0 hours being that which affects the observed declination of the sun when on the

meridian, commonly known as meridional refraction; the refraction for the hours just before and after noon is so nearly that of the meridian that it may be called and allowed as the same.

When the table is used, it must be borne in mind that when the declination is north or + in the table, the refraction is to be added; when the declination is south or —, the refraction must be subtracted.

It will be noticed that the refraction in south or — declination increases very rapidly as the sun nears the horizon, showing that observations should not be taken with the sun, when south of the equator, less than one hour from the horizon.

TABLE VII.—Pole Distances of Polaris.

1895.	1896.	1897.	1898.	1899.	1900.
1° 15′ 08″	1° 14′ 49″	1° 14′ 30″	1° 14′ 11″	1° 13′ 71″	1° 13′ 33″

TABLE VIII.—Azimuths of the Tangents, and Offsets in feet, to the Parallel.

Latitude.	1 MILE.		2 MILES.		3 MILES.		4 MILES.	
	Azimuth	Offset.	Azimuth.	Offset.	Azimuth.	Offset.	Azimuth.	Offset.
30°	89°59′30″	0.39	89°59′00″	1.54	89°58′30″	3.47	89°58′00″	6.17
35	24	0.47	58 47	1.87	11	4.20	57 34	7.47
40	16	0.56	33	2.24	57 49	5.03	06	8.95
45	08	0.67	16	2.66	24	5.99	56 32	10.65
50	58 58	0.79	57 56	3.17	56 54	7.13	55 53	12.68
	5 MILES.		6 MILES.		7 MILES.		8 MILES.	
	Azimuth.	Offset.	Azimuth.	Offset.	Azimuth.	Offset.	Azimuth.	Offset.
30°	89°57′30″	9.64	89°57′00″	13.88	89°56′30″	18.89	89°56′00″	24.67
35	56 57	11.68	56 22	16.81	55 45	22.89	55 09	29 89
40	22	13.98	55 38	20.11	54 55	27.40	54 11	35.78
45	55 40	16.64	54 48	23.96	53 56	32.61	43 04	42.59
50	54 51	19.80	53 49	28.52	52 47	38.82	51 45	50.70
	9 MILES.		10 MILES.		11 MILES.		12 MILES.	
	Azimuth.	Offset.	Azimuth.	Offset.	Azimuth.	Offset.	Azimuth.	Offset.
30°	89°55′30″	31.23	89°55′00″	38 55	89°54′30″	46.65	89°54′00″	55.52
35	54 32	37.83	53 56	46.71	53 20	56.62	52 43	67.26
40	53 28	45.29	52 44	55.91	52 00	67.65	51 17	80.51
45	52 12	53 91	51 20	66.55	50 28	80.53	49 36	95.84
50	50 43	64 17	49 41	79.22	48 39	95.86	47 37	114.08

Interpolate for offsets for other latitudes. For offsets for half-mile points, take one-fourth the offset for a point twice the distance of the half-mile point from the tangential point.

Thus, the offset for $3\frac{1}{2}$ miles=$\frac{1}{4}$ the offset for 7 miles.

SMITHSONIAN

GEOGRAPHICAL TABLES.

TABLE 1.

FOR CONVERTING U. S. WEIGHTS AND MEASURES.*

CUSTOMARY TO METRIC.

LINEAR.

	Inches to millimetres.	Feet to metres.	Yards to metres.	Miles to kilometres.
1 =	25.4001	0.304801	0.914402	1.60935
2 =	50.8001	0.609601	1.828804	3.21869
3 =	76.2002	0.914402	2.743205	4.82804
4 =	101.6002	1.219202	3.657607	6.43739
5 =	127.0003	1.524003	4.572009	8.04674
6 =	152.4003	1.828804	5.486411	9.65608
7 =	177.8004	2.133604	6.400813	11.26543
8 =	203.2004	2.438405	7.315215	12.87478
9 =	228.6005	2.743205	8.229616	14.48412

CAPACITY.

	Fluid drams to millilitres or cubic centimetres.	Fluid ounces to millilitres.	Quarts to litres.	Gallons to litres.
1 =	3.70	29.57	0.94636	3.78543
2 =	7.39	59.15	1.89272	7.57087
3 =	11.09	88.72	2.83908	11.35630
4 =	14.79	118.29	3.78543	15.14174
5 =	18.48	147.87	4.73179	18.92717
6 =	22.18	177.44	5.67815	22.71261
7 =	25.88	207.02	6.62451	26.49804
8 =	29.57	236.59	7.57087	30.28348
9 =	33.27	266.16	8.51723	34.06891

SQUARE.

	Square inches to square centimetres.	Square feet to square decimetres.	Square yards to square metres.	Acres to hectares.
1 =	6.452	9.290	0.836	0.4047
2 =	12.903	18.581	1.672	0.8094
3 =	19.355	27.871	2.508	1.2141
4 =	25.807	37.161	3.344	1.6187
5 =	32.258	46.452	4.181	2.0234
6 =	38.710	55.742	5.017	2.4281
7 =	45.161	65.032	5.853	2.8328
8 =	51.613	74.323	6.689	3.2375
9 =	58.065	83.613	7.525	3.6422

WEIGHT.

	Grains to milligrammes.	Avoirdupois ounces to grammes.	Avoirdupois pounds to kilogrammes.	Troy ounces to grammes.
1 =	64.7989	28.3495	0.45359	31.10348
2 =	129.5978	56.6991	0.90719	62.20696
3 =	194.3968	85.0486	1.36078	93.31044
4 =	259.1957	113.3981	1.81437	124.41392
5 =	323.9946	141.7476	2.26796	155.51740
6 =	388.7935	170.0972	2.72156	186.62088
7 =	453.5924	198.4467	3.17515	217.72437
8 =	518.3914	226.7962	3.62874	248.82785
9 =	583.1903	255.1457	4.08233	279.93133

CUBIC.

	Cubic inches to cubic centimetres.	Cubic feet to cubic metres.	Cubic yards to cubic metres.	Bushels to hectolitres.
1 =	16.387	0.02832	0.765	0.35239
2 =	32.774	0.05663	1.529	0.70479
3 =	49.161	0.08495	2.294	1.05718
4 =	65.549	0.11327	3.058	1.40957
5 =	81.936	0.14158	3.823	1.76196
6 =	98.323	0.16990	4.587	2.11436
7 =	114.710	0.19822	5.352	2.46675
8 =	131.097	0.22654	6.116	2.81914
9 =	147.484	0.25485	6.881	3.17154

1 Gunter's chain = 20.1168 metres.
1 sq. statute mile = 259.000 hectares.
1 fathom = 1.829 metres.
1 nautical mile = 1853.25 metres.
1 foot = 0.304801 metre, 9.4840158 log.
1 avoir. pound = 453.5924277 gram.
15432.35639 grains = 1 kilogramme.

The only authorized material standard of customary length is the Troughton scale belonging to this office, whose length at 59°.62 Fahr. conforms to the British standard. The yard in use in the United States is therefore equal to the British yard.

The only authorized material standard of customary weight is the Troy pound of the Mint. It is of brass of unknown density, and therefore not suitable for a standard of mass. It was derived from the British standard Troy pound of 1758 by direct comparison. The British Avoirdupois pound was also derived from the latter, and contains 7,000 grains Troy.

The grain Troy is therefore the same as the grain Avoirdupois, and the pound Avoirdupois in use in the United States is equal to the British pound Avoirdupois.

The British gallon = 4.54346 litres. The British bushel = 36.3477 litres.

The length of the nautical mile given above and adopted by the U. S. Coast and Geodetic Survey many years ago is defined as that of a minute of arc of a great circle of a sphere whose surface equals that of the earth (Clarke's Spheroid of 1866).

METRIC TO CUSTOMARY.

LINEAR.

	Metres to inches.	Metres to feet.	Metres to yards.	Kilometres to miles.
1 =	39·3700	3.28083	1·093611	0·62137
2 =	78·7400	6·56167	2·187222	1·24274
3 =	118·1100	9·84250	3·280833	1·86411
4 =	157·4800	13·12333	4·374444	2·48548
5 =	196·8500	16·40417	5·468056	3·10685
6 =	236·2200	19·68500	6·561667	3·72822
7 =	275·5900	22·96583	7·655278	4·34959
8 =	314·9600	26·24667	8·748889	4·97096
9 =	354·3300	29·52750	9.842500	5·59233

CAPACITY.

	Millilitres or cubic centimetres to fluid drams.	Centilitres to fluid ounces.	Litres to quarts.	Decalitres to gallons.	Hectolitres to bushels.
1 =	0·27	0·338	1·0567	2·6417	2·8377
2 =	0·54	0·676	2·1134	5·2834	5·6755
3 =	0·81	1·014	3·1700	7·9251	8·5132
4 =	1·08	1·353	4·2267	10·5668	11·3510
5 =	1·35	1·691	5·2834	13·2085	14·1887
6 =	1·62	2·029	6·3401	15·8502	17·0265
7 =	1·89	2·367	7·3968	18·4919	19·8642
8 =	2·16	2·705	8·4535	21·1336	22·7019
9 =	2·43	3·043	9·5101	23·7753	25·5397

SQUARE.

	Square centimetres to square inches.	Square metres to square feet.	Square metres to square yards.	Hectares to acres.
1 =	0·1550	10·764	1·196	2·471
2 =	0·3100	21·528	2·392	4·942
3 =	0·4650	32·292	3·588	7·413
4 =	0.6200	43·055	4·784	9·884
5 =	0·7750	53·819	5·980	12·355
6 =	0.9300	64·583	7·176	14·826
7 =	1·0850	75·347	8·372	17·297
8 =	1·2400	86·111	9·568	19·768
9 =	1·3950	96·875	10·764	22·239

WEIGHT.

	Milligrammes to grains.	Kilogrammes to grains.	Hectogrammes to ounces avoirdupois.	Kilogrammes to pounds avoirdupois.
1 =	0·01543	15432·36	3·5274	2·20462
2 =	0·03086	30864·71	7·0548	4·40924
3 =	0·04630	46297·07	10·5822	6·61387
4 =	0·06173	61729·43	14·1096	8·81849
5 =	0·07716	77161·78	17·6370	11·02311
6 =	0·09259	92594·14	21·1644	13·22773
7 =	0·10803	108026·49	24·6918	15·43236
8 =	0·12346	123458·85	28·2192	17·63698
9 =	0·13889	138891·21	31·7466	19·84160

CUBIC.

	Cubic centimetres to cubic inches.	Cubic decimetres to cubic inches.	Cubic metres to cubic feet.	Cubic metres to cubic yards.
1 =	0·0610	61·023	35·314	1·308
2 =	0·1220	122·047	70·629	2·616
3 =	0·1831	183·070	105·943	3·924
4 =	0·2441	244·094	141·258	5·232
5 =	0·3051	305·117	176·572	6·540
6 =	0·3661	366·140	211·887	7·848
7 =	0·4272	427·164	247·201	9·156
8 =	0·4882	488·187	282·516	10·464
9 =	0·5492	549·210	317·830	11·771

WEIGHT — (*continued*).

	Quintals to pounds av.	Milliers or tonnes to pounds av.	Kilogrammes to ounces Troy.
1 =	220·46	2204·6	32·1507
2 =	440·92	4409·2	64·3015
3 =	661·39	6613·9	96·4522
4 =	881·85	8818·5	128·6030
5 =	1102·31	11023·1	160·7537
6 =	1322·77	13227·7	192·9044
7 =	1543·24	15432·4	225·0552
8 =	1763·70	17637·0	257·2059
9 =	1984·16	19841·6	289·3567

By the concurrent action of the principal governments of the world an International Bureau of Weights and Measures has been established near Paris. Under the direction of the International Committee, two ingots were cast of pure platinum-iridium in the proportion of 9 parts of the former to 1 of the latter metal. From one of these a certain number of kilogrammes were prepared, from the other a definite number of metre bars. These standards of weight and length were intercompared, without preference, and certain ones were selected as International prototype standards. The others were distributed by lot, in September, 1889, to the different governments and are called National prototype standards. Those apportioned to the United States were received in 1890 and are in the keeping of this office.

The metric system was legalized in the United States in 1866.

The International Standard Metre is derived from the Mètre des Archives, and its length is defined by the distance between two lines at 0° Centigrade, on a platinum-iridium bar deposited at the International Bureau of Weights and Measures.

The International Standard Kilogramme is a mass of platinum-iridium deposited at the same place, and its weight in vacuo is the same as that of the Kilogramme des Archives.

The litre is equal to a cubic decimetre, and it is measured by the quantity of distilled water which, at its maximum density, will counterpoise the standard kilogramme in a vacuum, the volume of such a quantity of water being, as nearly as has been ascertained, equal to a cubic decimetre.

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
1	1000.000	1	1	1.0000	1.0000	0.00000
2	500.000	4	8	1.4142	1.2599	0.30103
3	333.333	9	27	1.7321	1.4422	0.47712
4	250.000	16	64	2.0000	1.5874	0.60206
5	200.000	25	125	2.2361	1.7100	0.69897
6	166.667	36	216	2.4495	1.8171	0.77815
7	142.857	49	343	2.6458	1.9129	0.84510
8	125.000	64	512	2.8284	2.0000	0.90309
9	111.111	81	729	3.0000	2.0801	0.95424
10	100.000	100	1000	3.1623	2.1544	1.00000
11	90.9091	121	1331	3.3166	2.2240	1.04139
12	83.3333	144	1728	3.4641	2.2894	1.07918
13	76.9231	169	2197	3.6056	2.3513	1.11394
14	71.4286	196	2744	3.7417	2.4101	1.14613
15	66.6667	225	3375	3.8730	2.4662	1.17609
16	62.5000	256	4096	4.0000	2.5198	1.20412
17	58.8235	289	4913	4.1231	2.5713	1.23045
18	55.5556	324	5832	4.2426	2.6207	1.25527
19	52.6316	361	6859	4.3589	2.6684	1.27875
20	50.0000	400	8000	4.4721	2.7144	1.30103
21	47.6190	441	9261	4.5826	2.7589	1.32222
22	45.4545	484	10648	4.6904	2.8020	1.34242
23	43.4783	529	12167	4.7958	2.8439	1.36173
24	41.6667	576	13824	4.8990	2.8845	1.38021
25	40.0000	625	15625	5.0000	2.9240	1.39794
26	38.4615	676	17576	5.0990	2.9625	1.41497
27	37.0370	729	19683	5.1962	3.0000	1.43136
28	35.7143	784	21952	5.2915	3.0366	1.44716
29	34.4828	841	24389	5.3852	3.0723	1.46240
30	33.3333	900	27000	5.4772	3.1072	1.47712
31	32.2581	961	29791	5.5678	3.1414	1.49136
32	31.2500	1024	32768	5.6569	3.1748	1.50515
33	30.3030	1089	35937	5.7446	3.2075	1.51851
34	29.4118	1156	39304	5.8310	3.2396	1.53148
35	28.5714	1225	42875	5.9161	3.2711	1.54407
36	27.7778	1296	46656	6.0000	3.3019	1.55630
37	27.0270	1369	50653	6.0828	3.3322	1.56820
38	26.3158	1444	54872	6.1644	3.3620	1.57978
39	25.6410	1521	59319	6.2450	3.3912	1.59106
40	25.0000	1600	64000	6.3246	3.4200	1.60206
41	24.3902	1681	68921	6.4031	3.4482	1.61278
42	23.8095	1764	74088	6.4807	3.4760	1.62325
43	23.2558	1849	79507	6.5574	3.5034	1.63347
44	22.7273	1936	85184	6.6332	3.5303	1.64345
45	22.2222	2025	91125	6.7082	3.5569	1.65321
46	21.7391	2116	97336	6.7823	3.5830	1.66276
47	21.2766	2209	103823	6.8557	3.6088	1.67210
48	20.8333	2304	110592	6.9282	3.6342	1.68124
49	20.4082	2401	117649	7.0000	3.6593	1.69020
50	20.0000	2500	125000	7.0711	3.6840	1.69897
51	19.6078	2601	132651	7.1414	3.7084	1.70757
52	19.2308	2704	140608	7.2111	3.7325	1.71600
53	18.8679	2809	148877	7.2801	3.7563	1.72428
54	18.5185	2916	157464	7.3485	3.7798	1.73239

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
55	18.1818	3025	166375	7.4162	3.8030	1.74036
56	17.8571	3136	175616	7.4833	3.8259	1.74819
57	17.5439	3249	185193	7.5498	3.8485	1.75587
58	17.2414	3364	195112	7.6158	3.8709	1.76343
59	16.9492	3481	205379	7.6811	3.8930	1.77085
60	16.6667	3600	216000	7.7460	3.9149	1.77815
61	16.3934	3721	226981	7.8102	3.9365	1.78533
62	16.1290	3844	238328	7.8740	3.9579	1.79239
63	15.8730	3969	250047	7.9373	3.9791	1.79934
64	15.6250	4096	262144	8.0000	4.0000	1.80618
65	15.3846	4225	274625	8.0623	4.0207	1.81291
66	15.1515	4356	287496	8.1240	4.0412	1.81954
67	14.9254	4489	300763	8.1854	4.0615	1.82607
68	14.7059	4624	314432	8.2462	4.0817	1.83251
69	14.4928	4761	328509	8.3066	4.1016	1.83885
70	14.2857	4900	343000	8.3666	4.1213	1.84510
71	14.0845	5041	357911	8.4261	4.1408	1.85126
72	13.8889	5184	373248	8.4853	4.1602	1.85733
73	13.6986	5329	389017	8.5440	4.1793	1.86332
74	13.5135	5476	405224	8.6023	4.1983	1.86923
75	13.3333	5625	421875	8.6603	4.2172	1.87506
76	13.1579	5776	438976	8.7178	4.2358	1.88081
77	12.9870	5929	456533	8.7750	4.2543	1.88649
78	12.8205	6084	474552	8.8318	4.2727	1.89209
79	12.6582	6241	493039	8.8882	4.2908	1.89763
80	12.5000	6400	512000	8.9443	4.3089	1.90309
81	12.3457	6561	531441	9.0000	4.3267	1.90849
82	12.1951	6724	551368	9.0554	4.3445	1.91381
83	12.0482	6889	571787	9.1104	4.3621	1.91908
84	11.9048	7056	592704	9.1652	4.3795	1.92428
85	11.7647	7225	614125	9.2195	4.3968	1.92942
86	11.6279	7396	636056	9.2736	4.4140	1.93450
87	11.4943	7569	658503	9.3274	4.4310	1.93952
88	11.3636	7744	681472	9.3808	4.4480	1.94448
89	11.2360	7921	704969	9.4340	4.4647	1.94939
90	11.1111	8100	729000	9.4868	4.4814	1.95424
91	10.9890	8281	753571	9.5394	4.4979	1.95904
92	10.8696	8464	778688	9.5917	4.5144	1.96379
93	10.7527	8649	804357	9.6437	4.5307	1.96848
94	10.6383	8836	830584	9.6954	4.5468	1.97313
95	10.5263	9025	857375	9.7468	4.5629	1.97772
96	10.4167	9216	884736	9.7980	4.5789	1.98227
97	10.3093	9409	912673	9.8489	4.5947	1.98677
98	10.2041	9604	941192	9.8995	4.6104	1.99123
99	10.1010	9801	970299	9.9499	4.6261	1.99564
100	10.0000	10000	1000000	10.0000	4.6416	2.00000
101	9.90099	10201	1030301	10.0499	4.6570	2.00432
102	9.80392	10404	1061208	10.0995	4.6723	2.00860
103	9.70874	10609	1092727	10.1489	4.6875	2.01284
104	9.61538	10816	1124864	10.1980	4.7027	2.01703
105	9.52381	11025	1157625	10.2470	4.7177	2.02119
106	9.43396	11236	1191016	10.2956	4.7326	2.02531
107	9.34579	11449	1225043	10.3441	4.7475	2.02938
108	9.25926	11664	1259712	10.3923	4.7622	2.03342
109	9.17431	11881	1295029	10.4403	4.7769	2.03743

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
110	9.09091	12100	1331000	10.4881	4.7914	2.04139
111	9.00901	12321	1367631	10.5357	4.8059	2.04532
112	8.92857	12544	1404928	10.5830	4.8203	2.04922
113	8.84956	12769	1442897	10.6301	4.8346	2.05308
114	8.77193	12996	1481544	10.6771	4.8488	2.05690
115	8.69565	13225	1520875	10.7238	4.8629	2.06070
116	8.62069	13456	1560896	10.7703	4.8770	2.06446
117	8.54701	13689	1601613	10.8167	4.8910	2.06819
118	8.47458	13924	1643032	10.8628	4.9049	2.07188
119	8.40336	14161	1685159	10.9087	4.9187	2.07555
120	8.33333	14400	1728000	10.9545	4.9324	2.07918
121	8.26446	14641	1771561	11.0000	4.9461	2.08279
122	8.19672	14884	1815848	11.0454	4.9597	2.08636
123	8.13008	15129	1860867	11.0905	4.9732	2.08991
124	8.06452	15376	1906624	11.1355	4.9866	2.09342
125	8.00000	15625	1953125	11.1803	5.0000	2.09691
126	7.93651	15876	2000376	11.2250	5.0133	2.10037
127	7.87402	16129	2048383	11.2694	5.0265	2.10380
128	7.81250	16384	2097152	11.3137	5.0397	2.10721
129	7.75194	16641	2146689	11.3578	5.0528	2.11059
130	7.69231	16900	2197000	11.4018	5.0658	2.11394
131	7.63359	17161	2248091	11.4455	5.0788	2.11727
132	7.57576	17424	2299968	11.4891	5.0916	2.12057
133	7.51880	17689	2352637	11.5326	5.1045	2.12385
134	7.46269	17956	2406104	11.5758	5.1172	2.12710
135	7.40741	18225	2460375	11.6190	5.1299	2.13033
136	7.35294	18496	2515456	11.6619	5.1426	2.13354
137	7.29927	18769	2571353	11.7047	5.1551	2.13672
138	7.24638	19044	2628072	11.7473	5.1676	2.13988
139	7.19424	19321	2685619	11.7898	5.1801	2.14301
140	7.14286	19600	2744000	11.8322	5.1925	2.14613
141	7.09220	19881	2803221	11.8743	5.2048	2.14922
142	7.04225	20164	2863288	11.9164	5.2171	2.15229
143	6.99301	20449	2924207	11.9583	5.2293	2.15534
144	6.94444	20736	2985984	12.0000	5.2415	2.15836
145	6.89655	21025	3048625	12.0416	5.2536	2.16137
146	6.84932	21316	3112136	12.0830	5.2656	2.16435
147	6.80272	21609	3176523	12.1244	5.2776	2.16732
148	6.75676	21904	3241792	12.1655	5.2896	2.17026
149	6.71141	22201	3307949	12.2066	5.3015	2.17319
150	6.66667	22500	3375000	12.2474	5.3133	2.17609
151	6.62252	22801	3442951	12.2882	5.3251	2.17898
152	6.57893	23104	3511808	12.3288	5.3368	2.18184
153	6.53595	23409	3581577	12.3693	5.3485	2.18469
154	6.49351	23716	3652264	12.4097	5.3601	2.18752
155	6.45161	24025	3723875	12.4499	5.3717	2.19033
156	6.41026	24336	3796416	12.4900	5.3832	2.19312
157	6.36943	24649	3869893	12.5300	5.3947	2.19590
158	6.32911	24964	3944312	12.5698	5.4061	2.19866
159	6.28931	25281	4019679	12.6095	5.4175	2.20140
160	6.25000	25600	4096000	12.6491	5.4288	2.20412
161	6.21118	25921	4173281	12.6886	5.4401	2.20683
162	6.17284	26244	4251528	12.7279	5.4514	2.20952
163	6.13497	26569	4330747	12.7671	5.4626	2.21219
164	6.09756	26896	4410944	12.8062	5.4737	2.21484

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
165	6.06061	27225	4492125	12.8452	5.4848	2.21748
166	6.02410	27556	4574296	12.8841	5.4959	2.22011
167	5.98802	27889	4657463	12.9228	5.5069	2.22272
168	5.95238	28224	4741632	12.9615	5.5178	2.22531
169	5.91716	28561	4826809	13.0000	5.5288	2.22789
170	5.88235	28900	4913000	13.0384	5.5397	2.23045
171	5.84795	29241	5000211	13.0767	5.5505	2.23300
172	5.81395	29584	5088448	13.1149	5.5613	2.23553
173	5.78035	29929	5177717	13.1529	5.5721	2.23805
174	5.74713	30276	5268024	13.1909	5.5828	2.24055
175	5.71429	30625	5359375	13.2288	5.5934	2.24304
176	5.68182	30976	5451776	13.2665	5.6041	2.24551
177	5.64972	31329	5545233	13.3041	5.6147	2.24797
178	5.61798	31684	5639752	13.3417	5.6252	2.25042
179	5.58659	32041	5735339	13.3791	5.6357	2.25285
180	5.55556	32400	5832000	13.4164	5.6462	2.25527
181	5.52486	32761	5929741	13.4536	5.6567	2.25768
182	5.49451	33124	6028568	13.4907	5.6671	2.26007
183	5.46448	33489	6128487	13.5277	5.6774	2.26245
184	5.43478	33856	6229504	13.5647	5.6877	2.26482
185	5.40541	34225	6331625	13.6015	5.6980	2.26717
186	5.37634	34596	6434856	13.6382	5.7083	2.26951
187	5.34759	34969	6539203	13.6748	5.7185	2.27184
188	5.31915	35344	6644672	13.7113	5.7287	2.27416
189	5.29101	35721	6751269	13.7477	5.7388	2.27646
190	5.26316	36100	6859000	13.7840	5.7489	2.27875
191	5.23560	36481	6967871	13.8203	5.7590	2.28103
192	5.20833	36864	7077888	13.8564	5.7690	2.28330
193	5.18135	37249	7189057	13.8924	5.7790	2.28556
194	5.15464	37636	7301384	13.9284	5.7890	2.28780
195	5.12821	38025	7414875	13.9642	5.7989	2.29003
196	5.10204	38416	7529536	14.0000	5.8088	2.29226
197	5.07614	38809	7645373	14.0357	5.8186	2.29447
198	5.05051	39204	7762392	14.0712	5.8285	2.29667
199	5.02513	39601	7880599	14.1067	5.8383	2.29885
200	5.00000	40000	8000000	14.1421	5.8480	2.30103
201	4.97512	40401	8120601	14.1774	5.8578	2.30320
202	4.95050	40804	8242408	14.2127	5.8675	2.30535
203	4.92611	41209	8365427	14.2478	5.8771	2.30750
204	4.90196	41616	8489664	14.2829	5.8868	2.30963
205	4.87805	42025	8615125	14.3178	5.8964	2.31175
206	4.85437	42436	8741816	14.3527	5.9059	2.31387
207	4.83092	42849	8869743	14.3875	5.9155	2.31597
208	4.80769	43264	8998912	14.4222	5.9250	2.31806
209	4.78469	43681	9129329	14.4568	5.9345	2.32015
210	4.76190	44100	9261000	14.4914	5.9439	2.32222
211	4.73934	44521	9393931	14.5258	5.9533	2.32428
212	4.71698	44944	9528128	14.5602	5.9627	2.32634
213	4.69484	45369	9663597	14.5945	5.9721	2.32838
214	4.67290	45796	9800344	14.6287	5.9814	2.33041
215	4.65116	46225	9938375	14.6629	5.9907	2.33244
216	4.62963	46656	10077696	14.6969	6.0000	2.33445
217	4.60829	47089	10218313	14.7309	6.0092	2.33646
218	4.58716	47524	10360232	14.7648	6.0185	2.33846
219	4.56621	47961	10503459	14.7986	6.0277	2.34044

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
220	4.54545	48400	10648000	14.8324	6.0368	2.34242
221	4.52489	48841	10793861	14.8661	6.0459	2.34439
222	4.50450	49284	10941048	14.8997	6.0550	2.34635
223	4.48431	49729	11089567	14.9332	6.0641	2.34830
224	4.46429	50176	11239424	14.9666	6.0732	2.35025
225	4.44444	50625	11390625	15.0000	6.0822	2.35218
226	4.42478	51076	11543176	15.0333	6.0912	2.35411
227	4.40529	51529	11697083	15.0665	6.1002	2.35603
228	4.38596	51984	11852352	15.0997	6.1091	2.35793
229	4.36681	52441	12008989	15.1327	6.1180	2.35984
230	4.34783	52900	12167000	15.1658	6.1269	2.36173
231	4.32900	53361	12326391	15.1987	6.1358	2.36361
232	4.31034	53824	12487168	15.2315	6.1446	2.36549
233	4.29185	54289	12649337	15.2643	6.1534	2.36736
234	4.27350	54756	12812904	15.2971	6.1622	2.36922
235	4.25532	55225	12977875	15.3297	6.1710	2.37107
236	4.23729	55696	13144256	15.3623	6.1797	2.37291
237	4.21941	56169	13312053	15.3948	6.1885	2.37475
238	4.20168	56644	13481272	15.4272	6.1972	2.37658
239	4.18410	57121	13651919	15.4596	6.2058	2.37840
240	4.16667	57600	13824000	15.4919	6.2145	2.38021
241	4.14938	58081	13997521	15.5242	6.2231	2.38202
242	4.13223	58564	14172488	15.5563	6.2317	2.38382
243	4.11523	59049	14348907	15.5885	6.2403	2.38561
244	4.09836	59536	14526784	15.6205	6.2488	2.38739
245	4.08163	60025	14706125	15.6525	6.2573	2.38917
246	4.06504	60516	14886936	15.6844	6.2658	2.39094
247	4.04858	61009	15069223	15.7162	6.2743	2.39270
248	4.03226	61504	15252992	15.7480	6.2828	2.39445
249	4.01606	62001	15438249	15.7797	6.2912	2.39620
250	4.00000	62500	15625000	15.8114	6.2996	2.39794
251	3.98406	63001	15813251	15.8430	6.3080	2.39967
252	3.96825	63504	16003008	15.8745	6.3164	2.40140
253	3.95257	64009	16194277	15.9060	6.3247	2.40312
254	3.93701	64516	16387064	15.9374	6.3330	2.40483
255	3.92157	65025	16581375	15.9687	6.3413	2.40654
256	3.90625	65536	16777216	16.0000	6.3496	2.40824
257	3.89105	66049	16974593	16.0312	6.3579	2.40993
258	3.87597	66564	17173512	16.0624	6.3661	2.41162
259	3.86100	67081	17373979	16.0935	6.3743	2.41330
260	3.84615	67600	17576000	16.1245	6.3825	2.41497
261	3.83142	68121	17779581	16.1555	6.3907	2.41664
262	3.81679	68644	17984728	16.1864	6.3988	2.41830
263	3.80228	69169	18191447	16.2173	6.4070	2.41996
264	3.78788	69696	18399744	16.2481	6.4151	2.42160
265	3.77358	70225	18609625	16.2788	6.4232	2.42325
266	3.75940	70756	18821096	16.3095	6.4312	2.42488
267	3.74532	71289	19034163	16.3401	6.4393	2.42651
268	3.73134	71824	19248832	16.3707	6.4473	2.42813
269	3.71747	72361	19465109	16.4012	6.4553	2.42975
270	3.70370	72900	19683000	16.4317	6.4633	2.43136
271	3.69004	73441	19902511	16.4621	6.4713	2.43297
272	3.67647	73984	20123648	16.4924	6.4792	2.43457
273	3.66300	74529	20346417	16.5227	6.4872	2.43616
274	3.64964	75076	20570824	16.5529	6.4951	2.43775

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
275	3.63636	75625	20796875	16.5831	6.5030	2.43933
276	3.62319	76176	21024576	16.6132	6.5108	2.44091
277	3.61011	76729	21253933	16.6433	6.5187	2.44248
278	3.59712	77284	21484952	16.6733	6.5265	2.44404
279	3.58423	77841	21717639	16.7033	6.5343	2.44560
280	3.57143	78400	21952000	16.7332	6.5421	2.44716
281	3.55872	78961	22188041	16.7631	6.5499	2.44871
282	3.54610	79524	22425768	16.7929	6.5577	2.45025
283	3.53357	80089	22665187	16.8226	6.5654	2.45179
284	3.52113	80656	22906304	16.8523	6.5731	2.45332
285	3.50877	81225	23149125	16.8819	6.5808	2.45484
286	3.49650	81796	23393656	16.9115	6.5885	2.45637
287	3.48432	82369	23639903	16.9411	6.5962	2.45788
288	3.47222	82944	23887872	16.9706	6.6039	2.45939
289	3.46021	83521	24137569	17.0000	6.6115	2.46090
290	3.44828	84100	24389000	17.0294	6.6191	2.46240
291	3.43643	84681	24642171	17.0587	6.6267	2.46389
292	3.42466	85264	24897088	17.0880	6.6343	2.46538
293	3.41297	85849	25153757	17.1172	6.6419	2.46687
294	3.40136	86436	25412184	17.1464	6.6494	2.46835
295	3.38983	87025	25672375	17.1756	6.6569	2.46982
296	3.37838	87616	25934336	17.2047	6.6644	2.47129
297	3.36700	88209	26198073	17.2337	6.6719	2.47276
298	3.35570	88804	26463592	17.2627	6.6794	2.47422
299	3.34448	89401	26730899	17.2916	6.6869	2.47567
300	3.33333	90000	27000000	17.3205	6.6943	2.47712
301	3.32226	90601	27270901	17.3494	6.7018	2.47857
302	3.31126	91204	27543608	17.3781	6.7092	2.48001
303	3.30033	91809	27818127	17.4069	6.7166	2.48144
304	3.28947	92416	28094464	17.4356	6.7240	2.48287
305	3.27869	93025	28372625	17.4642	6.7313	2.48430
306	3.26797	93636	28652616	17.4929	6.7387	2.48572
307	3.25733	94249	28934443	17.5214	6.7460	2.48714
308	3.24675	94864	29218112	17.5499	6.7533	2.48855
309	3.23625	95481	29503629	17.5784	6.7606	2.48996
310	3.22581	96100	29791000	17.6068	6.7679	2.49136
311	3.21543	96721	30080231	17.6352	6.7752	2.49276
312	3.20513	97344	30371328	17.6635	6.7824	2.49415
313	3.19489	97969	30664297	17.6918	6.7897	2.49554
314	3.18471	98596	30959144	17.7200	6.7969	2.49693
315	3.17460	99225	31255875	17.7482	6.8041	2.49831
316	3.16456	99856	31554496	17.7764	6.8113	2.49969
317	3.15457	100489	31855013	17.8045	6.8185	2.50106
318	3.14465	101124	32157432	17.8326	6.8256	2.50243
319	3.13480	101761	32461759	17.8606	6.8328	2.50379
320	3.12500	102400	32768000	17.8885	6.8399	2.50515
321	3.11527	103041	33076161	17.9165	6.8470	2.50651
322	3.10559	103684	33386248	17.9444	6.8541	2.50786
323	3.09598	104329	33698267	17.9722	6.8612	2.50920
324	3.08642	104976	34012224	18.0000	6.8683	2.51055
325	3.07692	105625	34328125	18.0278	6.8753	2.51188
326	3.06748	106276	34645976	18.0555	6.8824	2.51322
327	3.05810	106929	34965783	18.0831	6.8894	2.51455
328	3.04878	107584	35287552	18.1108	6.8964	2.51587
329	3.03951	108241	35611289	18.1384	6.9034	2.51720

TABLE 1.

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
330	3.03030	108900	35937000	18.1659	6.9104	2.51851
331	3.02115	109561	36264691	18.1934	6.9174	2.51983
332	3.01205	110224	36594368	18.2209	6.9244	2.52114
333	3.00300	110889	36926037	18.2483	6.9313	2.52244
334	2.99401	111556	37259704	18.2757	6.9382	2.52375
335	2.98507	112225	37595375	18.3030	6.9451	2.52504
336	2.97619	112896	37933056	18.3303	6.9521	2.52634
337	2.96736	113569	38272753	18.3576	6.9589	2.52763
338	2.95858	114244	38614472	18.3848	6.9658	2.52892
339	2.94985	114921	38958219	18.4120	6.9727	2.53020
340	2.94118	115600	39304000	18.4391	6.9795	2.53148
341	2.93255	116281	39651821	18.4662	6.9864	2.53275
342	2.92398	116964	40001688	18.4932	6.9932	2.53403
343	2.91545	117649	40353607	18.5203	7.0000	2.53529
344	2.90698	118336	40707584	18.5472	7.0068	2.53656
345	2.89855	119025	41063625	18.5742	7.0136	2.53782
346	2.89017	119716	41421736	18.6011	7.0203	2.53908
347	2.88184	120409	41781923	18.6279	7.0271	2.54033
348	2.87356	121104	42144192	18.6548	7.0338	2.54158
349	2.86533	121801	42508549	18.6815	7.0406	2.54283
350	2.85714	122500	42875000	18.7083	7.0473	2.54407
351	2.84900	123201	43243551	18.7350	7.0540	2.54531
352	2.84091	123904	43614208	18.7617	7.0607	2.54654
353	2.83286	124609	43986977	18.7883	7.0674	2.54777
354	2.82486	125316	44361864	18.8149	7.0740	2.54900
355	2.81690	126025	44738875	18.8414	7.0807	2.55023
356	2.80899	126736	45118016	18.8680	7.0873	2.55145
357	2.80112	127449	45499293	18.8944	7.0940	2.55267
358	2.79330	128164	45882712	18.9209	7.1006	2.55388
359	2.78552	128881	46268279	18.9473	7.1072	2.55509
360	2.77778	129600	46656000	18.9737	7.1138	2.55630
361	2.77008	130321	47045881	19.0000	7.1204	2.55751
362	2.76243	131044	47437928	19.0263	7.1269	2.55871
363	2.75482	131769	47832147	19.0526	7.1335	2.55991
364	2.74725	132496	48228544	19.0788	7.1400	2.56110
365	2.73973	133225	48627125	19.1050	7.1466	2.56229
366	2.73224	133956	49027896	19.1311	7.1531	2.56348
367	2.72480	134689	49430863	19.1572	7.1596	2.56467
368	2.71739	135424	49836032	19.1833	7.1661	2.56585
369	2.71003	136161	50243409	19.2094	7.1726	2.56703
370	2.70270	136900	50653000	19.2354	7.1791	2.56820
371	2.69542	137641	51064811	19.2614	7.1855	2.56937
372	2.68817	138384	51478848	19.2873	7.1920	2.57054
373	2.68097	139129	51895117	19.3132	7.1984	2.57171
374	2.67380	139876	52313624	19.3391	7.2048	2.57287
375	2.66667	140625	52734375	19.3649	7.2112	2.57403
376	2.65957	141376	53157376	19.3907	7.2177	2.57519
377	2.65252	142129	53582633	19.4165	7.2240	2.57634
378	2.64550	142884	54010152	19.4422	7.2304	2.57749
379	2.63852	143641	54439939	19.4679	7.2368	2.57864
380	2.63158	144400	54872000	19.4936	7.2432	2.57978
381	2.62467	145161	55306341	19.5192	7.2495	2.58092
382	2.61780	145924	55742968	19.5448	7.2558	2.58206
383	2.61097	146689	56181887	19.5704	7.2622	2.58320
384	2.60417	147456	56623104	19.5959	7.2685	2.58433

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
385	2.59740	148225	57066625	19.6214	7.2748	2.58546
386	2.59067	148996	57512456	19.6469	7.2811	2.58659
387	2.58398	149769	57960603	19.6723	7.2874	2.58771
388	2.57732	150544	58411072	19.6977	7.2936	2.58883
389	2.57069	151321	58863869	19.7231	7.2999	2.58995
390	2.56410	152100	59319000	19.7484	7.3061	2.59106
391	2.55754	152881	59776471	19.7737	7.3124	2.59218
392	2.55102	153664	60236288	19.7990	7.3186	2.59329
393	2.54453	154449	60698457	19.8242	7.3248	2.59439
394	2.53807	155236	61162984	19.8494	7.3310	2.59550
395	2.53165	156025	61629875	19.8746	7.3372	2.59660
396	2.52525	156816	62099136	19.8997	7.3434	2.59770
397	2.51889	157609	62570773	19.9249	7.3496	2.59879
398	2.51256	158404	63044792	19.9499	7.3558	2.59988
399	2.50627	159201	63521199	19.9750	7.3619	2.60097
400	2.50000	160000	64000000	20.0000	7.3681	2.60206
401	2.49377	160801	64481201	20.0250	7.3742	2.60314
402	2.48756	161604	64964808	20.0499	7.3803	2.60423
403	2.48139	162409	65450827	20.0749	7.3864	2.60531
404	2.47525	163216	65939264	20.0998	7.3925	2.60638
405	2.46914	164025	66430125	20.1246	7.3986	2.60746
406	2.46305	164836	66923416	20.1494	7.4047	2.60853
407	2.45700	165649	67419143	20.1742	7.4108	2.60959
408	2.45098	166464	67917312	20.1990	7.4169	2.61066
409	2.44499	167281	68417929	20.2237	7.4229	2.61172
410	2.43902	168100	68921000	20.2485	7.4290	2.61278
411	2.43309	168921	69426531	20.2731	7.4350	2.61384
412	2.42718	169744	69934528	20.2978	7.4410	2.61490
413	2.42131	170569	70444997	20.3224	7.4470	2.61595
414	2.41546	171396	70957944	20.3470	7.4530	2.61700
415	2.40964	172225	71473375	20.3715	7.4590	2.61805
416	2.40385	173056	71991296	20.3961	7.4650	2.61909
417	2.39808	173889	72511713	20.4206	7.4710	2.62014
418	2.39234	174724	73034632	20.4450	7.4770	2.62118
419	2.38663	175561	73560059	20.4695	7.4829	2.62221
420	2.38095	176400	74088000	20.4939	7.4889	2.62325
421	2.37530	177241	74618461	20.5183	7.4948	2.62428
422	2.36967	178084	75151448	20.5426	7.5007	2.62531
423	2.36407	178929	75686967	20.5670	7.5067	2.62634
424	2.35849	179776	76225024	20.5913	7.5126	2.62737
425	2.35294	180625	76765625	20.6155	7.5185	2.62839
426	2.34742	181476	77308776	20.6398	7.5244	2.62941
427	2.34192	182329	77854483	20.6640	7.5302	2.63043
428	2.33645	183184	78402752	20.6882	7.5361	2.63144
429	2.33100	184041	78953589	20.7123	7.5420	2.63246
430	2.32558	184900	79507000	20.7364	7.5478	2.63347
431	2.32019	185761	80062991	20.7605	7.5537	2.63448
432	2.31481	186624	80621568	20.7846	7.5595	2.63548
433	2.30947	187489	81182737	20.8087	7.5654	2.63649
434	2.30415	188356	81746504	20.8327	7.5712	2.63749
435	2.29885	189225	82312875	20.8567	7.5770	2.63849
436	2.29358	190096	82881856	20.8806	7.5828	2.63949
437	2.28833	190969	83453453	20.9045	7.5886	2.64048
438	2.28311	191844	84027672	20.9284	7.5944	2.64147
439	2.27790	192721	84604519	20.9523	7.6001	2.64246

TABLE 3.

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
440	2.27273	193600	85184000	20.9762	7.6059	2.64345
441	2.26757	194481	85766121	21.0000	7.6117	2.64444
442	2.26244	195364	86350888	21.0238	7.6174	2.64542
443	2.25734	196249	86938307	21.0476	7.6232	2.64640
444	2.25225	197136	87528384	21.0713	7.6289	2.64738
445	2.24719	198025	88121125	21.0950	7.6346	2.64836
446	2.24215	198916	88716536	21.1187	7.6403	2.64933
447	2.23714	199809	89314623	21.1424	7.6460	2.65031
448	2.23214	200704	89915392	21.1660	7.6517	2.65128
449	2.22717	201601	90518849	21.1896	7.6574	2.65225
450	2.22222	202500	91125000	21.2132	7.6631	2.65321
451	2.21730	203401	91733851	21.2368	7.6688	2.65418
452	2.21239	204304	92345408	21.2603	7.6744	2.65514
453	2.20751	205209	92959677	21.2838	7.6801	2.65610
454	2.20264	206116	93576664	21.3073	7.6857	2.65706
455	2.19780	207025	94196375	21.3307	7.6914	2.65801
456	2.19298	207936	94818816	21.3542	7.6970	2.65896
457	2.18818	208849	95443993	21.3776	7.7026	2.65992
458	2.18341	209764	96071912	21.4009	7.7082	2.66087
459	2.17865	210681	96702579	21.4243	7.7138	2.66181
460	2.17391	211600	97336000	21.4476	7.7194	2.66276
461	2.16920	212521	97972181	21.4709	7.7250	2.66370
462	2.16450	213444	98611128	21.4942	7.7306	2.66464
463	2.15983	214369	99252847	21.5174	7.7362	2.66558
464	2.15517	215296	99897344	21.5407	7.7418	2.66652
465	2.15054	216225	100544625	21.5639	7.7473	2.66745
466	2.14592	217156	101194696	21.5870	7.7529	2.66839
467	2.14133	218089	101847563	21.6102	7.7584	2.66932
468	2.13675	219024	102503232	21.6333	7.7639	2.67025
469	2.13220	219961	103161709	21.6564	7.7695	2.67117
470	2.12766	220900	103823000	21.6795	7.7750	2.67210
471	2.12314	221841	104487111	21.7025	7.7805	2.67302
472	2.11864	222784	105154048	21.7256	7.7860	2.67394
473	2.11416	223729	105823817	21.7486	7.7915	2.67486
474	2.10970	224677	106496424	21.7715	7.7970	2.67578
475	2.10526	225625	107171875	21.7945	7.8025	2.67669
476	2.10084	226576	107850176	21.8174	7.8079	2.67761
477	2.09644	227529	108531333	21.8403	7.8134	2.67852
478	2.09205	228484	109215352	21.8632	7.8188	2.67943
479	2.08768	229441	109902239	21.8861	7.8243	2.68034
480	2.08333	230400	110592000	21.9089	7.8297	2.68124
481	2.07900	231361	111284641	21.9317	7.8352	2.68215
482	2.07469	232324	111980168	21.9545	7.8406	2.68305
483	2.07039	233289	112678587	21.9773	7.8460	2.68395
484	2.06612	234256	113379904	22.0000	7.8514	2.68485
485	2.06186	235225	114084125	22.0227	7.8568	2.68574
486	2.05761	236196	114791256	22.0454	7.8622	2.68664
487	2.05339	237169	115501303	22.0681	7.8676	2.68753
488	2.04918	238144	116214272	22.0907	7.8730	2.68842
489	2.04499	239121	116930169	22.1133	7.8784	2.68931
490	2.04082	240100	117649000	22.1359	7.8837	2.69020
491	2.03666	241081	118370771	22.1585	7.8891	2.69108
492	2.03252	242064	119095488	22.1811	7.8944	2.69197
493	2.02840	243049	119823157	22.2036	7.8998	2.69285
494	2.02429	244036	120553784	22.2261	7.9051	2.69373

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
495	2.02020	245025	121287375	22.2486	7.9105	2.69461
496	2.01613	246016	122023936	22.2711	7.9158	2.69548
497	2.01207	247009	122763473	22.2935	7.9211	2.69636
498	2.00803	248004	123505992	22.3159	7.9264	2.69723
499	2.00401	249001	124251499	22.3383	7.9317	2.69810
500	2.00000	250000	125000000	22.3607	7.9370	2.69897
501	1.99601	251001	125751501	22.3830	7.9420	2.69984
502	1.99203	252004	126506008	22.4054	7.9476	2.70070
503	1.98807	253009	127263527	22.4277	7.9528	2.70157
504	1.98413	254016	128024064	22.4499	7.9581	2.70243
505	1.98020	255025	128787625	22.4722	7.9634	2.70329
506	1.97628	256036	129554216	22.4944	7.9686	2.70415
507	1.97239	257049	130323843	22.5167	7.9739	2.70501
508	1.96850	258064	131096512	22.5389	7.9791	2.70586
509	1.96464	259081	131872229	22.5610	7.9843	2.70672
510	1.96078	260100	132651000	22.5832	7.9896	2.70757
511	1.95695	261121	133432831	22.6053	7.9948	2.70842
512	1.95312	262144	134217728	22.6274	8.0000	2.70927
513	1.94932	263169	135005697	22.6495	8.0052	2.71012
514	1.94553	264196	135796744	22.6716	8.0104	2.71096
515	1.94175	265225	136590875	22.6936	8.0156	2.71181
516	1.93798	266256	137388096	22.7156	8.0208	2.71265
517	1.93424	267289	138188413	22.7376	8.0260	2.71349
518	1.93050	268324	138991832	22.7596	8.0311	2.71433
519	1.92678	269361	139798359	22.7816	8.0363	2.71517
520	1.92308	270400	140608000	22.8035	8.0415	2.71600
521	1.91939	271441	141420761	22.8254	8.0466	2.71684
522	1.91571	272484	142236648	22.8473	8.0517	2.71767
523	1.91205	273529	143055667	22.8692	8.0569	2.71850
524	1.90840	274576	143877824	22.8910	8.0620	2.71933
525	1.90476	275625	144703125	22.9129	8.0671	2.72016
526	1.90114	276676	145531576	22.9347	8.0723	2.72099
527	1.89753	277729	146363183	22.9565	8.0774	2.72181
528	1.89394	278784	147197952	22.9783	8.0825	2.72263
529	1.89036	279841	148035889	23.0000	8.0876	2.72346
530	1.88679	280900	148877000	23.0217	8.0927	2.72428
531	1.88324	281961	149721291	23.0434	8.0978	2.72509
532	1.87970	283024	150568768	23.0651	8.1028	2.72591
533	1.87617	284089	151419437	23.0868	8.1079	2.72673
534	1.87266	285156	152273304	23.1084	8.1130	2.72754
535	1.86916	286225	153130375	23.1301	8.1180	2.72835
536	1.86567	287296	153990656	23.1517	8.1231	2.72916
537	1.86220	288369	154854153	23.1733	8.1281	2.72997
538	1.85874	289444	155720872	23.1948	8.1332	2.73078
539	1.85529	290521	156590819	23.2164	8.1382	2.73159
540	1.85185	291600	157464000	23.2379	8.1433	2.73239
541	1.84843	292681	158340421	23.2594	8.1483	2.73320
542	1.84502	293764	159220088	23.2809	8.1533	2.73400
543	1.84162	294849	160103007	23.3024	8.1583	2.73480
544	1.83824	295936	160989184	23.3238	8.1633	2.73560
545	1.83486	297025	161878625	23.3452	8.1683	2.73640
546	1.83150	298116	162771336	23.3666	8.1733	2.73719
547	1.82815	299209	163667323	23.3880	8.1783	2.73799
548	1.82482	300304	164566592	23.4094	8.1833	2.73878
549	1.82149	301401	165469149	23.4307	8.1882	2.73957

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
550	1.81818	302500	166375000	23.4521	8.1932	2.74036
551	1.81488	303601	167284151	23.4734	8.1982	2.74115
552	1.81159	304704	168196608	23.4947	8.2031	2.74194
553	1.80832	305809	169112377	23.5160	8.2081	2.74273
554	1.80505	306916	170031464	23.5372	8.2130	2.74351
555	1.80180	308025	170953875	23.5584	8.2180	2.74429
556	1.79856	309136	171879616	23.5797	8.2229	2.74507
557	1.79533	310249	172808693	23.6008	8.2278	2.74586
558	1.79211	311364	173741112	23.6220	8.2327	2.74663
559	1.78891	312481	174676879	23.6432	8.2377	2.74741
560	1.78571	313600	175616000	23.6643	8.2426	2.74819
561	1.78253	314721	176558481	23.6854	8.2475	2.74896
562	1.77936	315844	177504328	23.7065	8.2524	2.74974
563	1.77620	316969	178453547	23.7276	8.2573	2.75051
564	1.77305	318096	179406144	23.7487	8.2621	2.75128
565	1.76991	319225	180362125	23.7697	8.2670	2.75205
566	1.76678	320356	181321496	23.7908	8.2719	2.75282
567	1.76367	321489	182284263	23.8118	8.2768	2.75358
568	1.76056	322624	183250432	23.8328	8.2816	2.75435
569	1.75747	323761	184220009	23.8537	8.2865	2.75511
570	1.75439	324900	185193000	23.8747	8.2913	2.75587
571	1.75131	326041	186169411	23.8956	8.2962	2.75664
572	1.74825	327184	187149248	23.9165	8.3010	2.75740
573	1.74520	328329	188132517	23.9374	8.3059	2.75815
574	1.74216	329476	189119224	23.9583	8.3107	2.75891
575	1.73913	330625	190109375	23.9792	8.3155	2.75967
576	1.73611	331776	191102976	24.0000	8.3203	2.76042
577	1.73310	332929	192100033	24.0208	8.3251	2.76118
578	1.73010	334084	193100552	24.0416	8.3300	2.76193
579	1.72712	335241	194104539	24.0624	8.3348	2.76268
580	1.72414	336400	195112000	24.0832	8.3396	2.76343
581	1.72117	337561	196122941	24.1039	8.3443	2.76418
582	1.71821	338724	197137368	24.1247	8.3491	2.76492
583	1.71527	339889	198155287	24.1454	8.3539	2.76567
584	1.71233	341056	199176704	24.1661	8.3587	2.76641
585	1.70940	342225	200201625	24.1868	8.3634	2.76716
586	1.70648	343396	201230056	24.2074	8.3682	2.76790
587	1.70358	344569	202262003	24.2281	8.3730	2.76864
588	1.70068	345744	203297472	24.2487	8.3777	2.76938
589	1.69779	346921	204336469	24.2693	8.3825	2.77012
590	1.69492	348100	205379000	24.2899	8.3872	2.77085
591	1.69205	349281	206425071	24.3105	8.3919	2.77159
592	1.68919	350464	207474688	24.3311	8.3967	2.77232
593	1.68634	351649	208527857	24.3516	8.4014	2.77305
594	1.68350	352836	209584584	24.3721	8.4061	2.77379
595	1.68067	354025	210644875	24.3926	8.4108	2.77452
596	1.67785	355216	211708736	24.4131	8.4155	2.77525
597	1.67504	356409	212776173	24.4336	8.4202	2.77597
598	1.67224	357604	213847192	24.4540	8.4249	2.77670
599	1.66945	358801	214921799	24.4745	8.4296	2.77743
600	1.66667	360000	216000000	24.4949	8.4343	2.77815
601	1.66389	361201	217081801	24.5153	8.4390	2.77887
602	1.66113	362404	218167208	24.5357	8.4437	2.77960
603	1.65837	363609	219256227	24.5561	8.4484	2.78032
604	1.65563	364816	220348864	24.5764	8.4530	2.78104

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
605	1.65289	366025	221445125	24.5967	8.4577	2.78176
606	1.65017	367236	222545016	24.6171	8.4623	2.78247
607	1.64745	368449	223648543	24.6374	8.4670	2.78319
608	1.64474	369664	224755712	24.6577	8.4716	2.78390
609	1.64204	370881	225866529	24.6779	8.4763	2.78462
610	1.63934	372100	226981000	24.6982	8.4809	2.78533
611	1.63666	373321	228099131	24.7184	8.4856	2.78604
612	1.63399	374544	229220928	24.7386	8.4902	2.78675
613	1.63132	375769	230346397	24.7588	8.4948	2.78746
614	1.62866	376996	231475544	24.7790	8.4994	2.78817
615	1.62602	378225	232608375	24.7992	8.5040	2.78888
616	1.62338	379456	233744896	24.8193	8.5086	2.78958
617	1.62075	380689	234885113	24.8395	8.5132	2.79029
618	1.61812	381924	236029032	24.8596	8.5178	2.79099
619	1.61551	383161	237176659	24.8797	8.5224	2.79169
620	1.61290	384400	238328000	24.8998	8.5270	2.79239
621	1.61031	385641	239483061	24.9199	8.5316	2.79309
622	1.60772	386884	240641848	24.9399	8.5362	2.79379
623	1.60514	388129	241804367	24.9600	8.5408	2.79449
624	1.60256	389376	242970624	24.9800	8.5453	2.79518
625	1.60000	390625	244140625	25.0000	8.5499	2.79934
626	1.59744	391876	245314376	25.0200	8.5544	2.79657
627	1.59490	393129	246491883	25.0400	8.5590	2.79727
628	1.59236	394384	247673152	25.0599	8.5635	2.79796
629	1.58983	395641	248858189	25.0799	8.5681	2.79865
630	1.58730	396900	250047000	25.0998	8.5726	2.79934
631	1.58479	398161	251239591	25.1197	8.5772	2.80003
632	1.58228	399424	252435968	25.1396	8.5817	2.80072
633	1.57978	400689	253636137	25.1595	8.5862	2.80140
634	1.57729	401956	254840104	25.1794	8.5907	2.80209
635	1.57480	403225	256047875	25.1992	8.5952	2.80277
636	1.57233	404496	257259456	25.2190	8.5997	2.80346
637	1.56986	405769	258474853	25.2389	8.6043	2.80414
638	1.56740	407044	259694072	25.2587	8.6088	2.80482
639	1.56495	408321	260917119	25.2784	8.6132	2.80550
640	1.56250	409600	262144000	25.2982	8.6177	2.80618
641	1.56006	410881	263374721	25.3180	8.6222	2.80686
642	1.55763	412164	264609288	25.3377	8.6267	2.80754
643	1.55521	413449	265847707	25.3574	8.6312	2.80821
644	1.55280	414736	267089984	25.3772	8.6357	2.80889
645	1.55039	416025	268336125	25.3969	8.6401	2.80956
646	1.54799	417316	269586136	25.4165	8.6446	2.81023
647	1.54560	418609	270840023	25.4362	8.6490	2.81090
648	1.54321	419904	272097792	25.4558	8.6535	2.81158
649	1.54083	421201	273359449	25.4755	8.6579	2.81224
650	1.53846	422500	274625000	25.4951	8.6624	2.81291
651	1.53610	423801	275894451	25.5147	8.6668	2.81358
652	1.53374	425104	277167808	25.5343	8.6713	2.81425
653	1.53139	426409	278445077	25.5539	8.6757	2.81491
654	1.52905	427716	279726264	25.5734	8.6801	2.81558
655	1.52672	429025	281011375	25.5930	8.6845	2.81624
656	1.52439	430336	282300416	25.6125	8.6890	2.81690
657	1.52207	431649	283593393	25.6320	8.6934	2.81757
658	1.51976	432964	284890312	25.6515	8.6978	2.81823
659	1.51745	434281	286191179	25.6710	8.7022	2.81889

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
660	1.51515	435600	287496000	25.6905	8.7066	2.81954
661	1.51286	436921	288804781	25.7099	8.7110	2.82020
662	1.51057	438244	290117528	25.7294	8.7154	2.82086
663	1.50830	439569	291434247	25.7488	8.7198	2.82151
664	1.50602	440896	292754944	25.7682	8.7241	2.82217
665	1.50376	442225	294079625	25.7876	8.7285	2.82282
666	1.50150	443556	295408296	25.8070	8.7329	2.82347
667	1.49925	444889	296740963	25.8263	8.7373	2.82413
668	1.49701	446224	298077632	25.8457	8.7416	2.82478
669	1.49477	447561	299418309	25.8650	8.7460	2.82543
670	1.49254	448900	300763000	25.8844	8.7503	2.82607
671	1.49031	450241	302111711	25.9037	8.7547	2.82672
672	1.48810	451584	303464448	25.9230	8.7590	2.82737
673	1.48588	452929	304821217	25.9422	8.7634	2.82802
674	1.48368	454276	306182024	25.9615	8.7677	2.82866
675	1.48148	455625	307546875	25.9808	8.7721	2.82930
676	1.47929	456976	308915776	26.0000	8.7764	2.82995
677	1.47710	458329	310288733	26.0192	8.7807	2.83059
678	1.47493	459684	311665752	26.0384	8.7850	2.83123
679	1.47275	461041	313046839	26.0576	8.7893	2.83187
680	1.47059	462400	314432000	26.0768	8.7937	2.83251
681	1.46843	463761	315821241	26.0960	8.7980	2.83315
682	1.46628	465124	317214568	26.1151	8.8023	2.83378
683	1.46413	466489	318611987	26.1343	8.8066	2.83442
684	1.46199	467856	320013504	26.1534	8.8108	2.83506
685	1.45985	469225	321419125	26.1725	8.8152	2.83569
686	1.45773	470596	322828856	26.1916	8.8194	2.83632
687	1.45560	471969	324242703	26.2107	8.8237	2.83696
688	1.45349	473344	325660672	26.2298	8.8280	2.83759
689	1.45138	474721	327082769	26.2488	8.8323	2.83822
690	1.44928	476100	328509000	26.2679	8.8366	2.83885
691	1.44718	477481	329939371	26.2869	8.8408	2.83948
692	1.44509	478864	331373888	26.3059	8.8451	2.84011
693	1.44300	480249	332812557	26.3249	8.8493	2.84073
694	1.44092	481636	334255384	26.3439	8.8536	2.84136
695	1.43885	483025	335702375	26.3629	8.8578	2.84198
696	1.43678	484416	337153536	26.3818	8.8621	2.84261
697	1.43472	485809	338608873	26.4008	8.8663	2.84323
698	1.43266	487204	340068392	26.4197	8.8706	2.84386
699	1.43062	488601	341532099	26.4386	8.8748	2.84448
700	1.42857	490000	343000000	26.4575	8.8790	2.84510
701	1.42653	491401	344472101	26.4764	8.8833	2.84572
702	1.42450	492804	345948408	26.4953	8.8875	2.84634
703	1.42248	494209	347428927	26.5141	8.8917	2.84696
704	1.42045	495616	348913664	26.5330	8.8959	2.84757
705	1.41844	497025	350402625	26.5518	8.9001	2.84819
706	1.41643	498436	351895816	26.5707	8.9043	2.84880
707	1.41443	499849	353393243	26.5895	8.9085	2.84942
708	1.41243	501264	354894912	26.6083	8.9127	2.85003
709	1.41044	502681	356400829	26.6271	8.9169	2.85065
710	1.40845	504100	357911000	26.6458	8.9211	2.85126
711	1.40647	505521	359425431	26.6646	8.9253	2.85187
712	1.40449	506944	360944128	26.6833	8.9295	2.85248
713	1.40252	508369	362467097	26.7021	8.9337	2.85309
714	1.40056	509796	363994344	26.7208	8.9378	2.85370

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
715	1.39860	511225	365525875	26.7395	8.9420	2.85431
716	1.39665	512656	367061696	26.7582	8.9462	2.85491
717	1.39470	514089	368601813	26.7769	8.9503	2.85552
718	1.39276	515524	370146232	26.7955	8.9545	2.85612
719	1.39082	516961	371694959	26.8142	8.9587	2.85673
720	1.38889	518400	373248000	26.8328	8.9628	2.85733
721	1.38696	519841	374805361	26.8514	8.9670	2.85794
722	1.38504	521284	376367048	26.8701	8.9711	2.85854
723	1.38313	522729	377933067	26.8887	8.9752	2.85914
724	1.38122	524176	379503424	26.9072	8.9794	2.85974
725	1.37931	525625	381078125	26.9258	8.9835	2.86034
726	1.37741	527076	382657176	26.9444	8.9876	2.86094
727	1.37552	528529	384240583	26.9629	8.9918	2.86153
728	1.37363	529984	385828352	26.9815	8.9959	2.86213
729	1.37174	531441	387420489	27.0000	9.0000	2.86273
730	1.36986	532900	389017000	27.0185	9.0041	2.86332
731	1.36799	534361	390617891	27.0370	9.0082	2.86392
732	1.36612	535824	392223168	27.0555	9.0123	2.86451
733	1.36426	537289	393832837	27.0740	9.0164	2.86510
734	1.36240	538756	395446904	27.0924	9.0205	2.86570
735	1.36054	540225	397065375	27.1109	9.0246	2.86629
736	1.35870	541696	398688256	27.1293	9.0287	2.86688
737	1.35685	543169	400315553	27.1477	9.0328	2.86747
738	1.35501	544644	401947272	27.1662	9.0369	2.86806
739	1.35318	546121	403583419	27.1846	9.0410	2.86864
740	1.35135	547600	405224000	27.2029	9.0450	2.86923
741	1.34953	549081	406869021	27.2213	9.0491	2.86982
742	1.34771	550564	408518488	27.2397	9.0532	2.87040
743	1.34590	552049	410172407	27.2580	9.0572	2.87099
744	1.34409	553536	411830784	27.2764	9.0613	2.87157
745	1.34228	555025	413493625	27.2947	9.0654	2.87216
746	1.34048	556516	415160936	27.3130	9.0694	2.87274
747	1.33869	558009	416832723	27.3313	9.0735	2.87332
748	1.33690	559504	418508992	27.3496	9.0775	2.87390
749	1.33511	561001	420189749	27.3679	9.0816	2.87448
750	1.33333	562500	421875000	27.3861	9.0856	2.87506
751	1.33156	564001	423564751	27.4044	9.0896	2.87564
752	1.32979	565504	425259008	27.4226	9.0937	2.87622
753	1.32802	567009	426957777	27.4408	9.0977	2.87679
754	1.32626	568516	428661064	27.4591	9.1017	2.87737
755	1.32450	570025	430368875	27.4773	9.1057	2.87795
756	1.32275	571536	432081216	27.4955	9.1098	2.87852
757	1.32100	573049	433798093	27.5136	9.1138	2.87910
758	1.31926	574564	435519512	27.5318	9.1178	2.87967
759	1.31752	576081	437245479	27.5500	9.1218	2.88024
760	1.31579	577600	438976000	27.5681	9.1258	2.88081
761	1.31406	579121	440711081	27.5862	9.1298	2.88138
762	1.31234	580644	442450728	27.6043	9.1338	2.88195
763	1.31062	582169	444194947	27.6225	9.1378	2.88252
764	1.30890	583696	445943744	27.6405	9.1418	2.88309
765	1.30719	585225	447697125	27.6586	9.1458	2.88366
766	1.30548	586756	449455096	27.6767	9.1498	2.88423
767	1.30378	588289	451217663	27.6948	9.1537	2.88480
768	1.30208	589824	452984832	27.7128	9.1577	2.88536
769	1.30039	591361	454756609	27.7308	9.1617	2.88593

TABLE 3.

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
770	1.29870	592900	456533000	27.7489	9.1657	2.88649
771	1.29702	594441	458314011	27.7669	9.1696	2.88705
772	1.29534	595984	460099648	27.7849	9.1736	2.88762
773	1.29366	597529	461889917	27.8029	9.1775	2.88818
774	1.29199	599076	463684824	27.8209	9.1815	2.88874
775	1.29032	600625	465484375	27.8388	9.1855	2.88930
776	1.28866	602176	467288576	27.8568	9.1894	2.88986
777	1.28700	603729	469097433	27.8747	9.1933	2.89042
778	1.28535	605284	470910952	27.8927	9.1973	2.89098
779	1.28370	606841	472729139	27.9106	9.2012	2.89154
780	1.28205	608400	474552000	27.9285	9.2052	2.89209
781	1.28041	609961	476379541	27.9464	9.2091	2.89265
782	1.27877	611524	478211768	27.9643	9.2130	2.89321
783	1.27714	613089	480048687	27.9821	9.2170	2.89376
784	1.27551	614656	481890304	28.0000	9.2209	2.89432
785	1.27389	616225	483736625	28.0179	9.2248	2.89487
786	1.27226	617796	485587656	28.0357	9.2287	2.89542
787	1.27065	619369	487443403	28.0535	9.2326	2.89597
788	1.26904	620944	489303872	28.0713	9.2365	2.89653
789	1.26743	622521	491169069	28.0891	9.2404	2.89708
790	1.26582	624100	493039000	28.1069	9.2443	2.89763
791	1.26422	625681	494913671	28.1247	9.2482	2.89818
792	1.26263	627264	496793088	28.1425	9.2521	2.89873
793	1.26103	628849	498677257	28.1603	9.2560	2.89927
794	1.25945	630436	500566184	28.1780	9.2599	2.89982
795	1.25786	632025	502459875	28.1957	9.2638	2.90037
796	1.25628	633616	504358336	28.2135	9.2677	2.90091
797	1.25471	635209	506261573	28.2312	9.2716	2.90146
798	1.25313	636804	508169592	28.2489	9.2754	2.90200
799	1.25156	638401	510082399	28.2666	9.2793	2.90255
800	1.25000	640000	512000000	28.2843	9.2832	2.90309
801	1.24844	641601	513922401	28.3019	9.2870	2.90363
802	1.24688	643204	515849608	28.3196	9.2909	2.90417
803	1.24533	644809	517781627	28.3373	9.2948	2.90472
804	1.24378	646416	519718464	28.3549	9.2986	2.90526
805	1.24224	648025	521660125	28.3725	9.3025	2.90580
806	1.24069	649636	523606616	28.3901	9.3063	2.90634
807	1.23916	651249	525557943	28.4077	9.3102	2.90687
808	1.23762	652864	527514112	28.4253	9.3140	2.90741
809	1.23609	654481	529475129	28.4429	9.3179	2.90795
810	1.23457	656100	531441000	28.4605	9.3217	2.90849
811	1.23305	657721	533411731	28.4781	9.3255	2.90902
812	1.23153	659344	535387328	28.4956	9.3294	2.90956
813	1.23001	660969	537367797	28.5132	9.3332	2.91009
814	1.22850	662596	539353144	28.5307	9.3370	2.91062
815	1.22699	664225	541343375	28.5482	9.3408	2.91116
816	1.22549	665856	543338496	28.5657	9.3447	2.91169
817	1.22399	667489	545338513	28.5832	9.3485	2.91222
818	1.22249	669124	547343432	28.6007	9.3523	2.91275
819	1.22100	670761	549353259	28.6182	9.3561	2.91328
820	1.21951	672400	551368000	28.6356	9.3599	2.91381
821	1.21803	674041	553387661	28.6531	9.3637	2.91434
822	1.21655	675684	555412248	28.6705	9.3675	2.91487
823	1.21507	677329	557441767	28.6880	9.3713	2.91540
824	1.21359	678976	559476224	28.7054	9.3751	2.91593

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
825	1.21212	680625	561515625	28.7228	9.3789	2.91645
826	1.21065	682276	563559976	28.7402	9.3827	2.91698
827	1.20919	683929	565609283	28.7576	9.3865	2.91751
828	1.20773	685584	567663552	28.7750	9.3902	2.91803
829	1.20627	687241	569722789	28.7924	9.3940	2.91855
830	1.20482	688900	571787000	28.8097	9.3978	2.91908
831	1.20337	690561	573856191	28.8271	9.4016	2.91960
832	1.20192	692224	575930368	28.8444	9.4053	2.92012
833	1.20048	693889	578009537	28.8617	9.4091	2.92065
834	1.19904	695556	580093704	28.8791	9.4129	2.92117
835	1.19760	697225	582182875	28.8964	9.4166	2.92169
836	1.19617	698896	584277056	28.9137	9.4204	2.92221
837	1.19474	700569	586376253	28.9310	9.4241	2.92273
838	1.19332	702244	588480472	28.9482	9.4279	2.92324
839	1.19190	703921	590589719	28.9655	9.4316	2.92376
840	1.19048	705600	592704000	28.9828	9.4354	2.92428
841	1.18906	707281	594823321	29.0000	9.4391	2.92480
842	1.18765	708964	596947688	29.0172	9.4429	2.92531
843	1.18624	710649	599077107	29.0345	9.4466	2.92583
844	1.18483	712336	601211584	29.0517	9.4503	2.92634
845	1.18343	714025	603351125	29.0689	9.4541	2.92686
846	1.18203	715716	605495736	29.0861	9.4578	2.92737
847	1.18064	717409	607645423	29.1033	9.4615	2.92788
848	1.17925	719104	609800192	29.1204	9.4652	2.92840
849	1.17786	720801	611960049	29.1376	9.4690	2.92891
850	1.17647	722500	614125000	29.1548	9.4727	2.92942
851	1.17509	724201	616295051	29.1719	9.4764	2.92993
852	1.17371	725904	618470208	29.1890	9.4801	2.93044
853	1.17233	727609	620650477	29.2062	9.4838	2.93095
854	1.17096	729316	622835864	29.2233	9.4875	2.93146
855	1.16959	731025	625026375	29.2404	9.4912	2.93197
856	1.16822	732736	627222016	29.2575	9.4949	2.93247
857	1.16686	734449	629422793	29.2746	9.4986	2.93298
858	1.16550	736164	631628712	29.2916	9.5023	2.93349
859	1.16414	737881	633839779	29.3087	9.5060	2.93399
860	1.16279	739600	636056000	29.3258	9.5097	2.93450
861	1.16144	741321	638277381	29.3428	9.5134	2.93500
862	1.16009	743044	640503928	29.3598	9.5171	2.93551
863	1.15875	744769	642735647	29.3769	9.5207	2.93601
864	1.15741	746496	644972544	29.3939	9.5244	2.93651
865	1.15607	748225	647214625	29.4109	9.5281	2.93702
866	1.15473	749956	649461896	29.4279	9.5317	2.93752
867	1.15340	751689	651714363	29.4449	9.5354	2.93802
868	1.15207	753424	653972032	29.4618	9.5391	2.93852
869	1.15075	755161	656234909	29.4788	9.5427	2.93902
870	1.14943	756900	658503000	29.4958	9.5464	2.93952
871	1.14811	758641	660776311	29.5127	9.5501	2.94002
872	1.14679	760384	663054848	29.5296	9.5537	2.94052
873	1.14548	762129	665338617	29.5466	9.5574	2.94101
874	1.14416	763876	667627624	29.5635	9.5610	2.94151
875	1.14286	765625	669921875	29.5804	9.5647	2.94201
876	1.14155	767376	672221376	29.5973	9.5683	2.94250
877	1.14025	769129	674526133	29.6142	9.5719	2.94300
878	1.13895	770884	676836152	29.6311	9.5756	2.94349
879	1.13766	772641	679151439	29.6479	9.5792	2.94399

TABLE 3.

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
880	1.13636	774400	681472000	29.6648	9.5828	2.94448
881	1.13507	776161	683797841	29.6816	9.5865	2.94498
882	1.13379	777924	686128968	29.6985	9.5901	2.94547
883	1.13250	779689	688465387	29.7153	9.5937	2.94596
884	1.13122	781456	690807104	29.7321	9.5973	2.94645
885	1.12994	783225	693154125	29.7489	9.6010	2.94694
886	1.12867	784996	695506456	29.7658	9.6046	2.94743
887	1.12740	786769	697864103	29.7825	9.6082	2.94792
888	1.12613	788544	700227072	29.7993	9.6118	2.94841
889	1.12486	790321	702595369	29.8161	9.6154	2.94890
890	1.12360	792100	704969000	29.8329	9.6190	2.94939
891	1.12233	793881	707347971	29.8496	9.6226	2.94988
892	1.12108	795664	709732288	29.8664	9.6262	2.95036
893	1.11982	797449	712121957	29.8831	9.6298	2.95085
894	1.11857	799236	714516984	29.8998	9.6334	2.95134
895	1.11732	801025	716917375	29.9166	9.6370	2.95182
896	1.11607	802816	719323136	29.9333	9.6406	2.95231
897	1.11483	804609	721734273	29.9500	9.6442	2.95279
898	1.11359	806404	724150792	29.9666	9.6477	2.95328
899	1.11235	808201	726572699	29.9833	9.6513	2.95376
900	1.11111	810000	729000000	30.0000	9.6549	2.95424
901	1.10988	811801	731432701	30.0167	9.6585	2.95472
902	1.10865	813604	733870808	30.0333	9.6620	2.95521
903	1.10742	815409	736314327	30.0500	9.6656	2.95569
904	1.10619	817216	738763264	30.0666	9.6692	2.95617
905	1.10497	819025	741217625	30.0832	9.6727	2.95665
906	1.10375	820836	743677416	30.0998	9.6763	2.95713
907	1.10254	822649	746142643	30.1164	9.6799	2.95761
908	1.10132	824464	748613312	30.1330	9.6834	2.95809
909	1.10011	826281	751089429	30.1496	9.6870	2.95856
910	1.09890	828100	753571000	30.1662	9.6905	2.95904
911	1.09769	829921	756058031	30.1828	9.6941	2.95952
912	1.09649	831744	758550528	30.1993	9.6976	2.95999
913	1.09529	833569	761048497	30.2159	9.7012	2.96047
914	1.09409	835396	763551944	30.2324	9.7047	2.96095
915	1.09290	837225	766060875	30.2490	9.7082	2.96142
916	1.09170	839056	768575296	30.2655	9.7118	2.96190
917	1.09051	840889	771095213	30.2820	9.7153	2.96237
918	1.08932	842724	773620632	30.2985	9.7188	2.96284
919	1.08814	844561	776151559	30.3150	9.7224	2.96332
920	1.08696	846400	778688000	30.3315	9.7259	2.96379
921	1.08578	848241	781229961	30.3480	9.7294	2.96426
922	1.08460	850084	783777448	30.3645	9.7329	2.96473
923	1.08342	851929	786330467	30.3809	9.7364	2.96520
924	1.08225	853776	788889024	30.3974	9.7400	2.96567
925	1.08108	855625	791453125	30.4138	9.7435	2.96614
926	1.07991	857476	794022776	30.4302	9.7470	2.96661
927	1.07875	859329	796597983	30.4467	9.7505	2.96708
928	1.07759	861184	799178752	30.4631	9.7540	2.96755
929	1.07643	863041	801765089	30.4795	9.7575	2.96802
930	1.07527	864900	804357000	30.4959	9.7610	2.96848
931	1.07411	866761	806954491	30.5123	9.7645	2.96895
932	1.07296	868624	809557568	30.5287	9.7680	2.96942
933	1.07181	870489	812166237	30.5450	9.7715	2.96988
934	1.07066	872356	814780504	30.5614	9.7750	2.97035

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
935	1.06952	874225	817400375	30.5778	9.7785	2.97081
936	1.06838	876096	820025856	30.5941	9.7819	2.97128
937	1.06724	877969	822656953	30.6105	9.7854	2.97174
938	1.06610	879844	825293672	30.6268	9.7889	2.97220
939	1.06496	881721	827936019	30.6431	9.7924	2.97267
940	1.06383	883600	830584000	30.6594	9.7959	2.97313
941	1.06270	885481	833237621	30.6757	9.7993	2.97359
942	1.06157	887364	835896888	30.6920	9.8028	2.97405
943	1.06045	889249	838561807	30.7083	9.8063	2.97451
944	1.05932	891136	841232384	30.7246	9.8097	2.97497
945	1.05820	893025	843908625	30.7409	9.8132	2.97543
946	1.05708	894916	846590536	30.7571	9.8167	2.97589
947	1.05597	896809	849278123	30.7734	9.8201	2.97635
948	1.05485	898704	851971392	30.7896	9.8236	2.97681
949	1.05374	900601	854670349	30.8058	9.8270	2.97727
950	1.05263	902500	857375000	30.8221	9.8305	2.97772
951	1.05152	904401	860085351	30.8383	9.8339	2.97818
952	1.05042	906304	862801408	30.8545	9.8374	2.97864
953	1.04932	908209	865523177	30.8707	9.8408	2.97909
954	1.04822	910116	868250664	30.8869	9.8443	2.97955
955	1.04712	912025	870983875	30.9031	9.8477	2.98000
956	1.04603	913936	873722816	30.9192	9.8511	2.98046
957	1.04493	915849	876467493	30.9354	9.8546	2.98091
958	1.04384	917764	879217912	30.9516	9.8580	2.98137
959	1.04275	919681	881974079	30.9677	9.8614	2.98182
960	1.04167	921600	884736000	30.9839	9.8648	2.98227
961	1.04058	923521	887503681	31.0000	9.8683	2.98272
962	1.03950	925444	890277128	31.0161	9.8717	2.98318
963	1.03842	927369	893056347	31.0322	9.8751	2.98363
964	1.03734	929296	895841344	31.0483	9.8785	2.98408
965	1.03627	931225	898632125	31.0644	9.8819	2.98453
966	1.03520	933156	901428696	31.0805	9.8854	2.98498
967	1.03413	935089	904231063	31.0966	9.8888	2.98543
968	1.03306	937024	907039232	31.1127	9.8922	2.98588
969	1.03199	938961	909853209	31.1288	9.8956	2.98632
970	1.03093	940900	912673000	31.1448	9.8990	2.98677
971	1.02987	942841	915498611	31.1609	9.9024	2.98722
972	1.02881	944784	918330048	31.1769	9.9058	2.98767
973	1.02775	946729	921167317	31.1929	9.9092	2.98811
974	1.02669	948676	924010424	31.2090	9.9126	2.98856
975	1.02564	950625	926859375	31.2250	9.9160	2.98900
976	1.02459	952576	929714176	31.2410	9.9194	2.98945
977	1.02354	954529	932574833	31.2570	9.9227	2.98989
978	1.02249	956484	935441352	31.2730	9.9261	2.99034
979	1.02145	958441	938313739	31.2890	9.9295	2.99078
980	1.02041	960400	941192000	31.3050	9.9329	2.99123
981	1.01937	962361	944076141	31.3209	9.9363	2.99167
982	1.01833	964324	946966168	31.3369	9.9396	2.99211
983	1.01729	966289	949862087	31.3528	9.9430	2.99255
984	1.01626	968256	952763904	31.3688	9.9464	2.99300
985	1.01523	970225	955671625	31.3847	9.9497	2.99344
986	1.01420	972196	958585256	31.4006	9.9531	2.99388
987	1.01317	974169	961504803	31.4166	9.9565	2.99432
988	1.01215	976144	964430272	31.4325	9.9598	2.99476
989	1.01112	978121	967361669	31.4484	9.9632	2.99520

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AND COMMON LOGARITHMS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	log. n
990	1.01010	980100	970299000	31.4643	9.9666	2.99564
991	1.00908	982081	973242271	31.4802	9.9699	2.99607
992	1.00806	984064	976191488	31.4960	9.9733	2.99651
993	1.00705	986049	979146657	31.5119	9.9766	2.99695
994	1.00604	988036	982107784	31.5278	9.9800	2.99739
995	1.00503	990025	985074875	31.5436	9.9833	2.99782
996	1.00402	992016	988047936	31.5595	9.9866	2.99826
997	1.00301	994009	991026973	31.5753	9.9900	2.99870
998	1.00200	996004	994011992	31.5911	9.9933	2.99913
999	1.00100	998001	997002999	31.6070	9.9967	2.99957
1000	1.00000	1000000	1000000000	31.6228	10.0000	3.00000

LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	Prop. Parts.								
											1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
N.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	Prop. Parts. 1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4
N.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

NATURAL SINES AND COSINES.

Natural Sines.

Angle.	0′	10′	20′	30′	40′	50′	60′	Angle.	Prop. Parts for 1′.
0°	.0000 00	.0029 09	.0058 18	.0087 27	.0116 35	.0145 44	.0174 52	**89°**	2.9
1	.0174 52	.0203 6	.0232 7	.0261 8	.0290 8	.0319 9	.0349 0	88	2.9
2	.0349 0	.0378 1	.0407 1	.0436 2	.0465 3	.0494 3	.0523 4	87	2.9
3	.0523 4	.0552 4	.0581 4	.0610 5	.0639 5	.0668 5	.0697 6	86	2.9
4	.0697 6	.0726 6	.0755 6	.0784 6	.0813 6	.0842 6	.0871 6	85	2.9
5	.0871 6	.0900 5	.0929 5	.0958 5	.0987 4	.1016 4	.1045 3	**84**	2.9
6	.1045 3	.1074 2	.1103 1	.1132 0	.1160 9	.1189 8	.1218 7	83	2.9
7	.1218 7	.1247 6	.1276 4	.1305 3	.1334	.1363	.1392	82	2.9
8	.1392	.1421	.1449	.1478	.1507	.1536	.1564	81	2.9
9	.1564	.1593	.1622	.1650	.1679	.1708	.1736	80	2.9
10	.1736	.1765	.1794	.1822	.1851	.1880	.1908	**79**	2.9
11	.1908	.1937	.1965	.1994	.2022	.2051	.2079	78	2.9
12	.2079	.2108	.2136	.2164	.2193	.2221	.2250	77	2.8
13	.2250	.2278	.2306	.2334	.2363	.2391	.2419	76	2.8
14	.2419	.2447	.2476	.2504	.2532	.2560	.2588	75	2.8
15	.2588	.2616	.2644	.2672	.2700	.2728	.2756	**74**	2.8
16	.2756	.2784	.2812	.2840	.2868	.2896	.2924	73	2.8
17	.2924	.2952	.2979	.3007	.3035	.3062	.3090	72	2.8
18	.3090	.3118	.3145	.3173	.3201	.3228	.3256	71	2.8
19	.3256	.3283	.3311	.3338	.3365	.3393	.3420	70	2.7
20	.3420	.3448	.3475	.3502	.3529	.3557	.3584	**69**	2.7
21	.3584	.3611	.3638	.3665	.3692	.3719	.3746	68	2.7
22	.3746	.3773	.3800	.3827	.3854	.3881	.3907	67	2.7
23	.3907	.3934	.3961	.3987	.4014	.4041	.4067	66	2.7
24	.4067	.4094	.4120	.4147	.4173	.4200	.4226	65	2.7
25	.4226	.4253	.4279	.4305	.4331	.4358	.4384	**64**	2.6
26	.4384	.4410	.4436	.4462	.4488	.4514	.4540	63	2.6
27	.4540	.4566	.4592	.4617	.4643	.4669	.4695	62	2.6
28	.4695	.4720	.4746	.4772	.4797	.4823	.4848	61	2.6
29	.4848	.4874	.4899	.4924	.4950	.4975	.5000	60	2.5
30	.5000	.5025	.5050	.5075	.5100	.5125	.5150	**59**	2.5
31	.5150	.5175	.5200	.5225	.5250	.5275	.5299	58	2.5
32	.5299	.5324	.5348	.5373	.5398	.5422	.5446	57	2.5
33	.5446	.5471	.5495	.5519	.5544	.5568	.5592	56	2.4
34	.5592	.5616	.5640	.5664	.5688	.5712	.5736	55	2.4
35	.5736	.5760	.5783	.5807	.5831	.5854	.5878	**54**	2.4
36	.5878	.5901	.5925	.5948	.5972	.5995	.6018	53	2.3
37	.6018	.6041	.6065	.6088	.6111	.6134	.6157	52	2.3
38	.6157	.6180	.6202	.6225	.6248	.6271	.6293	51	2.3
39	.6293	.6316	.6338	.6361	.6383	.6406	.6428	50	2.3
40	.6428	.6450	.6472	.6494	.6517	.6539	.6561	**49**	2.2
41	.6561	.6583	.6604	.6626	.6648	.6670	.6691	48	2.2
42	.6691	.6713	.6734	.6756	.6777	.6799	.6820	47	2.2
43	.6820	.6841	.6862	.6884	.6905	.6926	.6947	46	2.1
44	.6947	.6967	.6988	.7009	.7030	.7050	.7071	45	2.1
	60′	50′	40′	30′	20′	10′	0′	Angle.	

NATURAL SINES AND COSINES.

Natural Sines.

Angle.	0′	10′	20′	30′	40′	50′	60′	Angle.	Prop. Parts for 1′.
45°	.7071	.7092	.7112	.7133	.7153	.7173	.7193	**44°**	2.0
46	.7193	.7214	.7234	.7254	.7274	.7294	.7314	43	2.0
47	.7314	.7333	.7353	.7373	.7392	.7412	.7431	42	2.0
48	.7431	.7451	.7470	.7490	.7509	.7528	.7547	41	1.9
49	.7547	.7566	.7585	.7604	.7623	.7642	.7660	40	1.9
50	.7660	.7679	.7698	.7716	.7735	.7753	.7771	**39**	1.9
51	.7771	.7790	.7808	.7826	.7844	.7862	.7880	38	1.8
52	.7880	.7898	.7916	.7934	.7951	.7969	.7986	37	1.8
53	.7986	.8004	.8021	.8039	.8056	.8073	.8090	36	1.7
54	.8090	.8107	.8124	.8141	.8158	.8175	.8192	35	1.7
55	.8192	.8208	.8225	.8241	.8258	.8274	.8290	**34**	1.6
56	.8290	.8307	.8323	.8339	.8355	.8371	.8387	33	1.6
57	.8387	.8403	.8418	.8434	.8450	.8465	.8480	32	1.6
58	.8480	.8496	.8511	.8526	.8542	.8557	.8572	31	1.5
59	.8572	.8587	.8601	.8616	.8631	.8646	.8660	30	1.5
60	.8660	.8675	.8689	.8704	.8718	.8732	.8746	**29**	1.4
61	.8746	.8760	.8774	.8788	.8802	.8816	.8829	28	1.4
62	.8829	.8843	.8857	.8870	.8884	.8897	.8910	27	1.4
63	.8910	.8923	.8936	.8949	.8962	.8975	.8988	26	1.3
64	.8988	.9001	.9013	.9026	.9038	.9051	.9063	25	1.3
65	.9063	.9075	.9088	.9100	.9112	.9124	.9135	**24**	1.2
66	.9135	.9147	.9159	.9171	.9182	.9194	.9205	23	1.2
67	.9205	.9216	.9228	.9239	.9250	.9261	.9272	22	1.1
68	.9272	.9283	.9293	.9304	.9315	.9325	.9336	21	1.1
69	.9336	.9346	.9356	.9367	.9377	.9387	.9397	20	1.0
70	.9397	.9407	.9417	.9426	.9436	.9446	.9455	**19**	1.0
71	.9455	.9465	.9474	.9483	.9492	.9502	.9511	18	0.9
72	.9511	.9520	.9528	.9537	.9546	.9555	.9563	17	0.9
73	.9563	.9572	.9580	.9588	.9596	.9605	.9613	16	0.8
74	.9613	.9621	.9628	.9636	.9644	.9652	.9659	15	0.8
75	.9659	.9667	.9674	.9681	.9689	.9696	.9703	**14**	0.7
76	.9703	.9710	.9717	.9724	.9730	.9737	.9744	13	0.7
77	.9744	.9750	.9757	.9763	.9769	.9775	.9781	12	0.6
78	.9781	.9787	.9793	.9799	.9805	.9811	.9816	11	0.6
79	.9816	.9822	.9827	.9833	.9838	.9843	.9848	10	0.5
80	.9848	.9853	.9858	.9863	.9868	.9872	.9877	**9**	0.5
81	.9877	.9881	.9886	.9890	.9894	.9899	.9903	8	0.4
82	.9903	.9907	.9911	.9914	.9918	.9922	.9925	7	0.4
83	.9925	.9929	.9932	.9936	.9939	.9942	.9945	6	0.3
84	.9945	.9948	.9951	.9954	.9957	.9959	.9962	5	0.3
85	.9962	.9964	.9967	.9969	.9971	.9974	.9976	**4**	0.2
86	.9976	.9978	.9980	.9981	.9983	.9985	.9986	3	0.2
87	.9986	.9988	.9989	.9990	.9992	.9993	.9994	2	0.1
88	.9994	.9995	.9996	.9997	.9997	.9998	.9998	1	0.1
89	.9998	.9999	.9999	1.0000	1.0000	1.0000	1.0000	0	0.0
	60′	50′	40′	30′	20′	10′	0′	Angle.	

NATURAL TANGENTS AND COTANGENTS.

Natural Tangents.

Angle.	0′	10′	20′	30′	40′	50′	60′	Angle.	Prop. Parts for 1′.
0°	.0000 0	.0029 1	.0058 2	.0087 3	.0116 4	.0145 5	.0174 6	89°	2.9
1	.0174 6	.0203 6	.0232 8	.0261 9	.0291 0	.0320 1	.0349 2	88	2.9
2	.0349 2	.0378 3	.0407 5	.0436 6	.0465 8	.0494 9	.0524 1	87	2.9
3	.0524 1	.0553 3	.0582 4	.0611 6	.0640 8	.0670 0	.0699 3	86	2.9
4	.0699 3	.0728 5	.0757 8	.0787 0	.0816 3	.0845 6	.0874 9	85	2.9
5	.0874 9	.0904 2	.0933 5	.0962 9	.0992 3	.1021 6	.1051 0	84	2.9
6	.1051 0	.1080 5	.1109 9	.1139 4	.1168 8	.1198 3	.1227 8	83	2.9
7	.1227 8	.1257 4	.1286 9	.1316 5	.1346	.1376	.1405	82	3.0
8	.1405	.1435	.1465	.1495	.1524	.1554	.1584	81	3.0
9	.1584	.1614	.1644	.1673	.1703	.1733	.1763	80	3.0
10	.1763	.1793	.1823	.1853	.1883	.1914	.1944	79	3.0
11	.1944	.1974	.2004	.2035	.2065	.2095	.2126	78	3.0
12	.2126	.2156	.2186	.2217	.2247	.2278	.2309	77	3.1
13	.2309	.2339	.2370	.2401	.2432	.2462	.2493	76	3.1
14	.2493	.2524	.2555	.2586	.2617	.2648	.2679	75	3.1
15	.2679	.2711	.2742	.2773	.2805	.2836	.2867	74	3.1
16	.2867	.2899	.2931	.2962	.2994	.3026	.3057	73	3.2
17	.3057	.3089	.3121	.3153	.3185	.3217	.3249	72	3.2
18	.3249	.3281	.3314	.3346	.3378	.3411	.3443	71	3.2
19	.3443	.3476	.3508	.3541	.3574	.3607	.3640	70	3.3
20	.3640	.3673	.3706	.3739	.3772	.3805	.3839	69	3.3
21	.3839	.3872	.3906	.3939	.3973	.4006	.4040	68	3.4
22	.4040	.4074	.4108	.4142	.4176	.4210	.4245	67	3.4
23	.4245	.4279	.4314	.4348	.4383	.4417	.4452	66	3.5
24	.4452	.4487	.4522	.4557	.4592	.4628	.4663	65	3.5
25	.4663	.4699	.4734	.4770	.4806	.4841	.4877	64	3.6
26	.4877	.4913	.4950	.4986	.5022	.5059	.5095	63	3.6
27	.5095	.5132	.5169	.5206	.5243	.5280	.5317	62	3.7
28	.5317	.5354	.5392	.5430	.5467	.5505	.5543	61	3.8
29	.5543	.5581	.5619	.5658	.5696	.5735	.5774	60	3.8
30	.5774	.5812	.5851	.5890	.5930	.5969	.6009	59	3.9
31	.6009	.6048	.6088	.6128	.6168	.6208	.6249	58	4.0
32	.6249	.6289	.6330	.6371	.6412	.6453	.6494	57	4.1
33	.6494	.6536	.6577	.6619	.6661	.6703	.6745	56	4.2
34	.6745	.6787	.6830	.6873	.6916	.6959	.7002	55	4.3
35	.7002	.7046	.7089	.7133	.7177	.7221	.7265	54	4.4
36	.7265	.7310	.7355	.7400	.7445	.7490	.7536	53	4.5
37	.7536	.7581	.7627	.7673	.7720	.7766	.7813	52	4.6
38	.7813	.7860	.7907	.7954	.8002	.8050	.8098	51	4.7
39	.8098	.8146	.8195	.8243	.8292	.8342	.8391	50	4.9
40	.8391	.8441	.8491	.8541	.8591	.8642	.8693	49	5.0
41	.8693	.8744	.8796	.8847	.8899	.8952	.9004	48	5.2
42	.9004	.9057	.9110	.9163	.9217	.9271	.9325	47	5.4
43	.9325	.9380	.9435	.9490	.9545	.9601	.9657	46	5.5
44	.9657	.9713	.9770	.9827	.9884	.9942	1.0000	45	5.7
	60′	50′	40′	30′	20′	10′	0′	Angle.	

Natural Cotangents.

NATURAL TANGENTS AND COTANGENTS.

Natural Tangents.

Angle.	0′	10′	20′	30′	40′	50′	60′	Angle.	Prop. Parts for 1′.
45°	1.0000	1.0058	1.0117	1.0176	1.0235	1.0295	1.0355	**44°**	5.9
46	1.0355	1.0416	1.0477	1.0538	1.0599	1.0661	1.0724	43	6.1
47	1.0724	1.0786	1.0850	1.0913	1.0977	1.1041	1.1106	42	6.4
48	1.1106	1.1171	1.1237	1.1303	1.1369	1.1436	1.1504	41	6.6
49	1.1504	1.1571	1.1640	1.1708	1.1778	1.1847	1.1918	40	6.9
50	1.1918	1.1988	1.2059	1.2131	1.2203	1.2276	1.2349	**39**	7.2
51	1.2349	1.2423	1.2497	1.2572	1.2647	1.2723	1.2799	38	7.5
52	1.2799	1.2876	1.2954	1.3032	1.3111	1.3190	1.3270	37	7.9
53	1.3270	1.3351	1.3432	1.3514	1.3597	1.3680	1.3764	36	8.2
54	1.3764	1.3848	1.3934	1.4019	1.4106	1.4193	1.4281	35	8.6
55	1.4281	1.4370	1.4460	1.4550	1.4641	1.4733	1.4826	**34**	9.1
56	1.4826	1.4919	1.5013	1.5108	1.5204	1.5301	1.5399	33	9.6
57	1.5399	1.5497	1.5597	1.5697	1.5798	1.5900	1.6003	32	10.1
58	1.6003	1.6107	1.6212	1.6319	1.6426	1.6534	1.6643	31	10.7
59	1.6643	1.6753	1.6864	1.6977	1.7090	1.7205	1.7321	30	11.3
60	1.7321	1.7437	1.7556	1.7675	1.7796	1.7917	1.8040	**29**	12.0
61	1.8040	1.8165	1.8291	1.8418	1.8546	1.8676	1.8807	28	12.8
62	1.8807	1.8940	1.9074	1.9210	1.9347	1.9486	1.9626	27	13.6
63	1.9626	1.9768	1.9912	2.0057	2.0204	2.0353	2.0503	26	14.6
64	2.0503	2.0655	2.0809	2.0965	2.1123	2.1283	2.1445	25	15.7
65	2.1445	2.1609	2.1775	2.1943	2.2113	2.2286	2.2460	**24**	16.9
66	2.2460	2.2637	2.2817	2.2998	2.3183	2.3369	2.3559	23	18.3
67	2.3559	2.3750	2.3945	2.4142	2.4342	2.4545	2.4751	22	19.9
68	2.4751	2.4960	2.5172	2.5386	2.5605	2.5826	2.6051	21	21.7
69	2.6051	2.6279	2.6511	2.6746	2.6985	2.7228	2.7475	20	23.7
70	2.7475	2.7725	2.7980	2.8239	2.8502	2.8770	2.9042	**19**	
71	2.9042	2.9319	2.9600	2.9887	3.0178	3.0475	3.0777	18	
72	3.0777	3.1084	3.1397	3.1716	3.2041	3.2371	3.2709	17	
73	3.2709	3.3052	3.3402	3.3759	3.4124	3.4495	3.4874	16	
74	3.4874	3.5261	3.5656	3.6059	3.6470	3.6891	3.7321	15	
75	3.7321	3.7760	3.8208	3.8667	3.9136	3.9617	4.0108	**14**	
76	4.0108	4.0611	4.1126	4.1653	4.2193	4.2747	4.3315	13	
77	4.3315	4.3897	4.4494	4.5107	4.5736	4.6382	4.7046	12	
78	4.7046	4.7729	4.8430	4.9152	4.9894	5.0658	5.1446	11	
79	5.1446	5.2257	5.3093	5.3955	5.4845	5.5764	5.6713	10	
80	5.6713	5.7694	5.8708	5.9758	6.0844	6.1970	6.3138	**9**	
81	6.3138	6.4348	6.5606	6.6912	6.8269	6.9682	7.1154	8	
82	7.1154	7.2687	7.4287	7.5958	7.7704	7.9530	8.1443	7	
83	8.1443	8.3450	8.5555	8.7769	9.0098	9.2553	9.5144	6	
84	9.5144	9.7882	10.0780	10.3854	10.7119	11.0594	11.4301	5	
85	11.4301	11.8262	12.2505	12.7062	13.1969	13.7267	14.3007	**4**	
86	14.3007	14.9244	15.6048	16.3499	17.1693	18.0750	19.0811	3	
87	19.0811	20.2056	21.4704	22.9038	24.5418	26.4316	28.6363	2	
88	28.6363	31.2416	34.3678	38.1885	42.9641	49.1039	57.2900	1	
89	57.2900	68.7501	85.9398	114.5887	171.8854	343.7737	∞	0	
	60′	50′	40′	30′	20′	10′	0′	Angle.	

Natural Cotangents.

MEAN REFRACTION.

Apparent altitude.	Refraction.		Apparent altitude.	Refraction.		Apparent altitude.	Refraction.		Apparent altitude.	Refraction.		Apparent altitude.	Refraction.	
° ′	′ ″	″	° ′	° ″	″	° ′	′ ″	″	° ′	′ ″	″	°	″	″
0 0	34 54.1	124.9	7 0	7 19.7	9.2	14 0	3 47.4	5.3	28 0	1 48.2	1.5	42	64.0	2.2
10	32 49.2	116.9	10	7 10.5	8.8	20	3 42.1	5.1	20	1 46.7	1.4	43	61.8	2.1
20	30 52.3	108.8	20	7 1.7	8.4	40	3 37.0	4.9	40	1 45.3	1.5	44	59.7	2.0
30	29 3.5	100.8	30	6 53.3	8.2	15 0	3 32.1	4.7	29 0	1 43.8	1.4	45	57.7	2.0
40	27 22.7	92.9	40	6 45.1	7.9	20	3 27.4	4.5	20	1 42.4	1.4	46	55.7	1.9
50	25 49.8	85.2	50	6 37.2	7.6	40	3 22.9	4.3	40	1 41.0	1.3	47	53.8	1.9
1 0	24 24.6	77.9	8 0	6 29.6	7.3	16 0	3 18.6	4.1	30 0	1 39.7	1.3	48	51.9	1.7
10	23 6.7	71.1	10	6 22.3	7.1	20	3 14.5	4.0	20	1 38.4	1.3	49	50.2	1.8
20	21 55.6	64.7	20	6 15.2	6.8	40	3 10.5	3.9	40	1 37.1	1.3	50	48.4	1.7
30	20 50.9	59.0	30	6 8.4	6.6	17 0	3 6.6	3.7	31 0	1 35.8	1.3	51	46.7	1.6
40	19 51.9	53.9	40	6 1.8	6.4	20	3 2.9	3.6	20	1 34.5	1.2	52	45.1	1.6
50	18 58.0	49.4	50	5 55.4	6.1	40	2 59.3	3.5	40	1 33.3	1.2	53	43.5	1.6
2 0	18 8.6	45.6	9 0	5 49.3	6.0	18 0	2 55.8	3.3	32 0	1 32.1	1.2	54	41.9	1.5
10	17 23.0	42.3	10	5 43.3	5.7	20	2 52.5	3.2	20	1 30.9	1.1	55	40.4	1.5
20	16 40.7	39.8	20	5 37.6	5.6	40	2 49.3	3.2	40	1 29.8	1.1	56	38.9	1.4
30	16 0.9	37.5	30	5 32.0	5.5	19 0	2 46.1	3.0	33 0	1 28.7	1.1	57	37.5	1.4
40	15 23.4	35.0	40	5 26.5	5.2	20	2 43.1	2.9	20	1 27.6	1.1	58	36.1	1.4
50	14 47.8	33.2	50	5 21.3	5.1	40	2 40.2	2.9	40	1 26.5	1.1	59	34.7	1.4
3 0	14 14.6	30.9	10 0	5 16.2	5.0	20 0	2 37.3	2.8	34 0	1 25.4	1.1	60	33.3	1.3
10	13 43.7	28.7	10	5 11.2	4.8	20	2 34.5	2.6	20	1 24.3	1.0	61	32.0	1.3
20	13 15.0	26.7	20	5 6.4	4.7	40	2 31.9	2.6	40	1 23.3	1.0	62	30.7	1.3
30	12 48.3	24.6	30	5 1.7	4.5	21 0	2 29.3	2.5	35 0	1 22.3	1.0	63	29.4	1.2
40	12 23.7	23.0	40	4 57.2	4.4	20	2 26.8	2.5	20	1 21.3	1.0	64	28.2	1.3
50	12 0.7	21.8	50	4 52.8	4.3	40	2 24.3	2.4	40	1 20.3	1.0	65	26.9	1.2
4 0	11 38.9	20.6	11 0	4 48.5	4.2	22 0	2 21.9	2.3	36 0	1 19.3	1.0	66	25.7	1.2
10	11 18.3	19.7	10	4 44.3	4.1	20	2 19.6	2.2	20	1 18.3	0.9	67	24.5	1.2
20	10 58.6	19.0	20	4 40.2	3.9	40	2 17.4	2.2	40	1 17.4	0.9	68	23.3	1.1
30	10 39.6	18.4	30	4 36.3	3.9	23 0	2 15.2	2.2	37 0	1 16.5	0.9	69	22.2	1.2
40	10 21.2	17.9	40	4 32.4	3.7	20	2 13.0	2.1	20	1 15.6	0.9	70	21.0	1.1
50	10 3.3	16.8	50	4 28.7	3.7	40	2 10.9	2.0	40	1 14.7	0.9	71	19.9	1.1
5 0	9 46.5	15.6	12 0	4 25.0	3.6	24 0	2 8.9	1.9	38 0	1 13.8	0.9	72	18.8	1.1
10	9 30.9	14.9	10	4 21.4	3.4	20	2 7.0	1.9	20	1 12.9	0.9	73	17.7	1.1
20	9 16.0	14.1	20	4 18.0	3.4	40	2 5.1	1.9	40	1 12.0	0.8	74	16.6	1.1
30	9 1.9	13.5	30	4 14.6	3.3	25 0	2 3.2	1.8	39 0	1 11.2	0.9	75	15.5	1.0
40	8 48.4	12.8	40	4 11.3	3.2	20	2 1.4	1.8	20	1 10.3	0.8	76	14.5	1.1
50	8 35.6	12.3	50	4 8.1	3.2	40	1 59.6	1.8	40	1 9.5	0.8	77	13.4	1.1
6 0	8 23.3	11.7	13 0	4 4.9	3.1	26 0	1 57.8	1.7	40 0	1 8.7	0.8	78	12.3	1.1
10	8 11.6	11.3	10	4 1.8	3.0	20	1 56.1	1.7	20	1 7.9	0.8	79	11.2	1.0
20	8 0.3	10.8	20	3 58.8	2.9	40	1 54.4	1.6	40	1 7.1	0.8	80	10.2	1.1
30	7 49.5	10.3	30	3 55.9	2.9	27 0	1 52.8	1.6	41 0	1 6.3	0.8	81	9.1	1.0
40	7 39.2	10.0	40	3 53.0	2.8	20	1 51.2	1.5	20	1 5.5	0.8	82	8.1	4.0
50	7 29.2	9.5	50	3 50.2	2.8	40	1 49.7	1.5	40	1 4.7	0.7	86	4.1	4.1
7 0	7 19.7		14 0	3 47.4		28 0	1 48.2		42 0	1 4.0		90	0.0	

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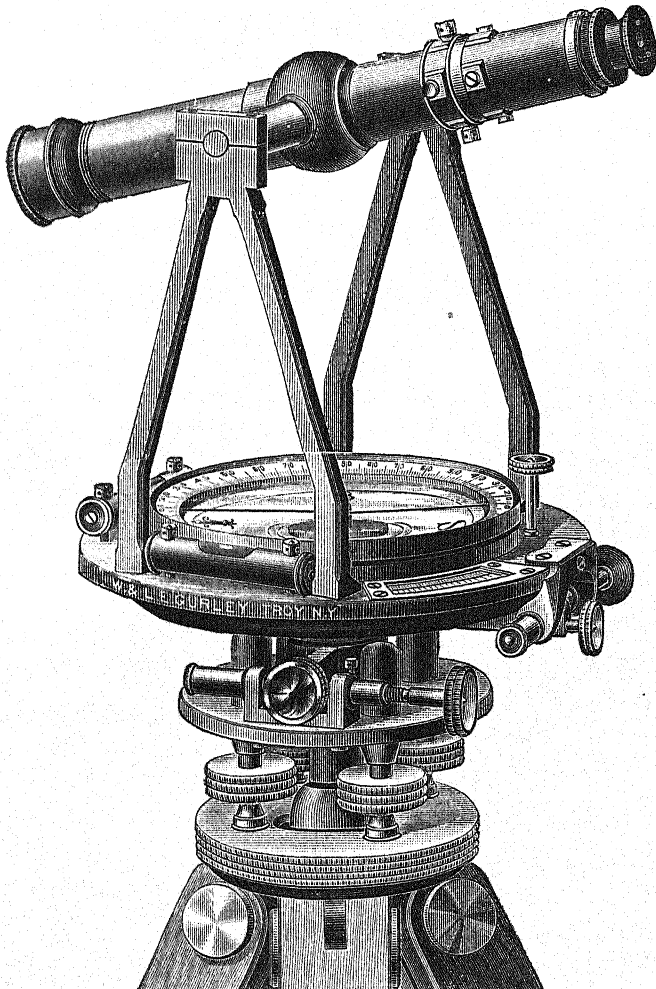
W. & L. E. GURLEY TROY N.Y.

TABLE 6.

Books must be returned within one month of date of issue. Per Reg : Post

Date of Issue	Return.	Date of Issue.	Return.